PELICAN BOOKS

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AN OUTLINE OF THE UNIVERSE (II)

BY J. G. CROWTHER

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PELICAN BOOKS

AN OUTLINE OF THE UNIVERSE

BY

J. G. CROWTHER

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AN OUTLINE OF THE UNIVERSE

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CELLS

Bacteria do not require complicated food for their diet. They are able to build up their living tissue from raw chemicals, in some cases without assistance even from sunlight. This feat of organising comparatively simple chemicals into living structures might well absorb all the potentialities of a bacterium and leave none free to develop in other directions. If some bacterium-like organism succeeded in shortening the all-absorbing process of organising living bodies out of simple chemicals, it might have more energy to spare for novel developments. How could it shorten the process? By getting other organisms to do a part of the constructive chemistry for it. Let these turn raw chemicals into some of the complicated substances of which living bodies are made and then eat them. The feat of digestion would be enormously easier if other organisms had already done half the work of building up the complicated substances of life.

This fork in the possible direction of evolution from organisms of bacteria-like character appears early in the hierarchy of living organisms though not in the history of life. The Earth was probably stocked for many ages with organisms that had not learnt the trick of parasitically saving digestive labour at the expense of other organisms. These evolved into plants, which have developed the bacteria-like ability of assimilating simple chemical substances.

But plants, which have improved and not revolutionised the technique of building up living from dead matter, have only extended their size and variety and not introduced a new mode of living.

What must an organism do if it is to save constructive digestive labour by eating organisms already made of complicated substances? It must be capable of occupying a place liable to bear the organisms on which it feeds. It must in general be able to go to that place and catch the organism, and for this it needs the ability to move about.

The organisms rather larger than bacteria and consequently revealed in some detail by the microscope are of two roughly distinct types, those that for feeding purposes have no capacity of their own for movement and are merely carried around by the water or air in which they live, and those that have some power of self-movement even if only that of shaking hairs rhythmically.

For practical purposes a division of types in this way is very useful, if not completely comprehensive. More accurately, the difference is decided by the method of building up the material of the plant. If the cell contains chlorophyll and employs sunlight for building-up, it is a plant; if not, it is animal.

This difference in way of life has caused one end of the evolutionary fork to bear oak-trees and the other end man. In the long run its influence has been very great, but in spite of the great potentiality of this difference, it is not the most important characteristic noticed in the investigation of the tiniest living organisms whose structure is apparent in some detail.

Microscopic study of these small organisms shows they have certain common features whether they live the vegetative life of constructing tissue out of raw chemicals or the animal life of digesting other organisms,

or their products. They have definite boundaries in space. For instance, the speck of living jelly called the amoeba, though its shape is always changing, has definite boundaries and a fairly narrow range of volume. The organism moves by exuding parts of itself and enclosing matter suitable for food. In IV it has formed a cavity in order to encase a meal. Two structures are noticeable within the organism. There is a dark spot and a clear round spot. The first is named the nucleus and the second the vacuole. As time passes the vacuole expands and bursts, its contents being ejected through the

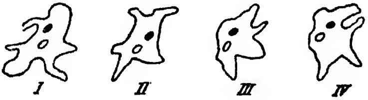


FIG. 72.

outer boundary of the amoeba. Then another little vacuole appears as a point within the fluid bulk, expands, bursts and is replaced again. The contents of the vacuole have been proved to be water and the operation to be physical in character. Water can permeate from the outside into the inside of the amoeba but cannot take the salts in the outer water with them. If the inflowing water were not periodically ejected the amoeba would burst. The phenomenon is osmotic in character. The dissolved particles of salt drum on the inner surface of the amoeba and cannot pass out into the surrounding water. The water permeates into the cell without obstruction and raises the internal pressure and volume of liquid, and has to be let out again to relieve the pressure. When the bulk of water injected is embarrassing to the organism, it is squirted out. The behaviour of surfaces is of fundamental importance in living organisms. The nature of the surface determines what passes through it.

Since surfaces are by no means always visible, interchanges and reactions may be happening vigorously on them and yet show nothing to mark their scene. Probably there are a large number of invisible surfaces inside the fluid part of the amoeba which allow some substances to pass through and others not. Such an arrangement could give many parts of the fluid bulk very different jobs to do and chemical reactions to supervise. The permeations at coarse obvious surfaces such as the boundary of the organism are perhaps only a few in an innumerable number occurring in the translucent fluid.

The importance of the difference between fluids on different sides of amoeba surfaces is learnt by studying the effects of changing the chemical constitution of the environing liquid. If drops of solutions useful to the organism are introduced into the liquid the amoeba will exude its body towards the parts of strongest concentration. *If the solution is inimical it will shrink* away. Those activities can fairly well be deduced from the mere physical properties of the dissolved substances and do not seem necessarily to depend on any specifically vital property in the amoeba.

Far more obviously remarkable than these small movements are the reproductive actions of amoebae. In the course of time the amoeba's dark spot is seen to elongate and grow dumb-bell shaped. Then the dumb-bell ends separate and the amoeba as a whole becomes dumb-bell shaped, with the masses of the ends roughly centred round the two portions of the nucleus. The separation becomes more and more defined until only a thread joins the parts, and then this snaps and the two ends shrink into their respective parts. Two amoebae are seen now where there was only one before.

The extraordinary stability of this change in an incessantly changing object is the great problem.

Stability in the midst of instability is the characteristic of life. The chemical reactions in even the amoeba must be very complicated and carefully interrelated to be so reliably self-governing. A steam-plant can be made self-governing so that the boiler-pressure controls the amount of water and the mixture of fuel and air fed

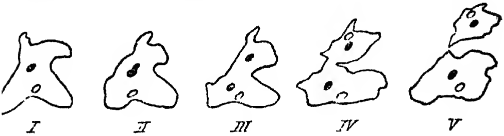


Fig. 73.

into the plant. The apparatus is not simple and is easily disorganised, while the amoeba's self-government has persisted through its species for aeons of time.

Small organisms with but one nucleus abound in thousands of forms. There are many modes of life even for these simple organisms. The structure of *Stylonychia* is evidently complicated, and it also has smaller organisms parasitic upon it (fig. 74).

Organisms apparently consisting only of a boundary with a nucleus and some inconspicuous internal structure are never more than about one quarter of an inch in diameter. The system of boundary, body-fluid, nucleus and invisible structures will not work if the organism is larger. We may suppose the limit depends on the ratio between the surface and the volume of the organism. As the diameter increases, the surface increases rapidly, but the volume even more rapidly. Hence in a large organism a very great deal of body fluid would have to do its business with the outer world through a relatively small surface area. The large organism would tend to be throttled or congested.

If amoeba-like organisms wish to develop beyond the quarter-of-an-inch stage they must use some new

method of development. They are apparently constrained by the laws of proportion from developing by growing into large amoebae of football size, for example.

The first stage of further development is co-operative. The small organisms can improve their prospects by forming aggregations and making feeding motions in common. They may cause a current of water bearing

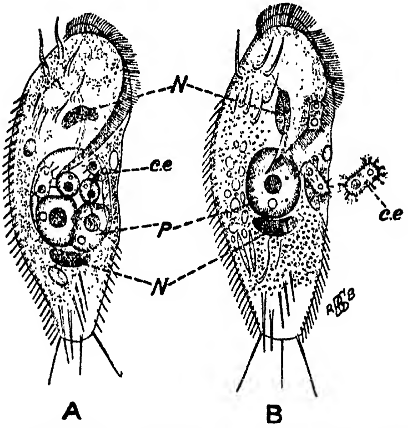


FIG. 74. *Stylonychia.* (From Minchin ? *Introduction to Study of Protozoa.* Arnold.)

food to flow towards them with a strength and reliability none of the organisers could guarantee for itself. If they are attached together simply into a structure they are not individually at the mercy of general currents in the water and do not have to compete with many other types of organisms for convenient feeding spots on neighbouring surfaces not exposed to scouring currents. By attaching themselves together and orientating in the same direction the colony can swim with greater momen-

tum and hence straighter and in less time to any desirable place.

The strength of such a colony is derived simply from probability. If many organisms are making similar motions the colony as a whole will act at the average rate of all. As a whole it will never be at rest, for if some members of the colony happen to be doing less than their share others will be doing more. The colonial behaviour will be steady and derive the associated advantage of never being caught napping.

The next complication in the life of simple organisms is provided by specialisation and division of labour. Some members of the colony devote themselves to feeding and others to reproduction, each becoming more efficient at their particular jobs than they could be as jacks-of-all-activities. Once specialisation has commenced the possibilities are enormous. The organisms on the outside of the colony can devote themselves to locomotion and protection, and those inside to digestion. The colony itself becomes an organism made up of many individuals having a primitive skin and viscera or digestive system.

Many small organisms show on microscopic examination that they consist of a number of parts each containing what looks like the nucleus of an amoeba. The small organism *Hydra* found in fresh-water ponds is seen essentially to be a hollow object with two layers of units each containing a nucleus. As these units are part of a larger body, they are often called cells (Plate XXa). When food comes within the grasp of the tentacles it is propelled by them into the cavity, and held and digested by the cells in the cavity surface. The organisation is so simple that the same cell may at one time be both holding as a muscle and digesting, holding and feeding at the same time.

When larger organisms are studied the subdivision

into cells is very much less evident. There are enormous differences in shape between cells from different parts of the body, and it is not easy to realise at once that these extraordinarily different-looking cells nevertheless have, generally speaking, only one nucleus, in spite of their complication. The knowledge that living bodies are made of multitudes of cells each similar in fundamentals with all other cells is not a hundred years old.

The great differences between the cells from different organs of the body of any high animal is due to extreme specialisation. For instance, the nerve-threads in a nerve are generally threads growing out of cells in the spinal cord which contain one nucleus. The thread may be several yards long. Such an extreme shape is not easily recognised as a unit. Other cells are engaged in exuding calcium carbonate and phosphate to make bone. The bones of animals are the petrified exudations from certain of its cells. Gristle consists of cells embedded in layers of gelatinous matter they have exuded. The intestine is layered with flat cells which absorb nutriment from its contents.

The kidney is made of cells which filter the blood and remove impurities and poisons. Cells in the liver conduct the most elaborate chemical operations in manufacturing complex substances from the products absorbed by cells in the stomach and intestine from food. The thyroid and other glands contain cells capable of producing special chemicals of great vital potency.

That the higher organisms consist of co-operative groups of individual cell-specialists has been proved most strikingly in recent years by the invention of tissue-culturing. If a small piece of the skin, kidney, brain, or any other tissue is cut away from an organism and placed in serum (the clear fluid left over when blood clots), the tissue may remain alive for some time. If the serum is carefully kept free from bacteria and at the

temperature to which the tissue is used, as, for example, 98·4° F. if it is from a man, the tissue lives vigorously. After a day or two the waste-products poison the serum too much for growth to continue, but if part of the culture is taken out, washed and placed into some fresh serum this continues to grow as vigorously as before. The support of the living processes when the tissue is away from its parental body is remarkable but still more, the cells in the tissue culture are kept in sufficiently healthy condition to be able to reproduce. From time to time, cells in the culture divide and the new cell drifts off into a free existence in the serum fluid. When the number of cells has become too great some can be taken out to start another culture. By fostering the succeeding generations of cells a tissue can be kept for many years, and apparently for ever. Cells from a hen, for instance, have been cultivated continuously for fourteen years: three times the period of the average hen's life.

In tissue-cultures the behaviour of cells freed from the constraints of their environment can be observed. It much resembles that of the amoeba.

The cell taken from the embryo of a chick is wandering in serum. Like the amoeba it has no definite shape but has a definite boundary which is always changing its contour by pushing out parts after the amoeba's manner. There is a nucleus in the cell, oil globules, and wriggling rods called mitochrondia, among the more discernible objects. The whole cell is about half a thousandth of an inch in diameter (Plate XXI).

Cells taken from different organs of a living body do not generate in culture copies of themselves. A nerve-cell with the long neurones or nerve-threads growing out of it does not generate cells with equally long threads, nor a muscle-cell cells which have the same range of capacity for rapid changes in size. The offspring of

cells cultured in serum tend to be uniform in design and to resemble amoebae. This most interesting fact indicates that the cell is capable of adapting itself to its environment. If it was generated in a muscle, it grows up muscle-like, if free to move in serum it grows up amoeba-like. Evidently cells growing in conjunction have a controlling influence on each other. Some experiments of Mangold demonstrate this prettily. He takes a portion of tissue from the brain of an embryo frog less than two days old and transplants it on to the skin of another embryo. When the second embryo matures, the transplanted tissue is found to have become incorporated into the animal's skin and is definitely changed from brain to skin tissue. But if the piece of brain tissue is four days old before transplantation it is not assimilated by the skin-cells and continues to develop into a brain. Consequently, the second embryo matures with an extra brain growing on its chest! More remarkable, the brain-cells compel the adjacent skin-cells on the embryo to become incorporated into the brain and contribute parts not inherent in the transplant. For instance, suppose the part of the brain associated with the eye is transplanted, and no other part. Besides the eye growing on the transplant other associated structures will appear round it. The eye-cells of the first embryo appear to have the power to change some of the skin-cells of the second embryo into head-cells to accompany the transplanted eye.

This modifying influence of adjacent cells on each other suggests why in tissue-cultures the offspring grow less and less like their ancestors. It seems to show, too, that organisms might be very much more plastic than we imagine, that great changes in the apparently fundamental properties of animals are possible, and that science is not so far from discovering methods of modifying the biological fundaments of living organisms

and producing original creatures quite different from any before known.

These experiments suggest, also, that the secret of cancer may prove to be a defect in the mechanism by which cells induce each other to form a harmonious whole. Some of them have cast off the harmonising influence of their neighbours and grown independently, forming tumours malignant or otherwise.

XXIX

REPRODUCTION

The reproduction of organisms by themselves is perhaps the most remarkable property of life. In the single cell the structure is so small that microscopy has given little more than a description of the process. Careful study reveals a few more objects in the cell besides the nucleus and containing fluid. For simplicity cell material is called protoplasm, but this word must not

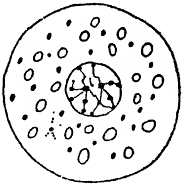


Fig. 75.

be thought to refer to one substance. The fluids in different cells are of different constitution, but have common characteristics comprehended by the general term protoplasm. The fluid outside the nucleus is called the cytoplasm.

The nucleus of the cell is found to contain a granular

stringy structure easily dyed to a dark colour, and called chromatin for this reason. The chromatin seems to be distributed about the nucleus as if it were concentrated at the surfaces of a packing of liquid bubbles or vacuoles.

The cytoplasm contains sundry granules and oil-bubbles, and there is also near the nucleus a small granule called the centrosome which is prominent in cell division. When the cell begins to divide the chro-

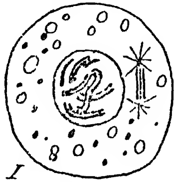


FIG. 76.

matin network in the nucleus becomes much more continuous in appearance and arranges itself into coils. Each of these short coils splits along its length into two, as in fig. 76. At the same time the centrosome particle in the cytoplasm outside the nucleus has split into two,

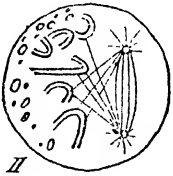


FIG. 77.

so that there are two star-shaped figures with lines of some kind joining them.

Then the parallel strings of split chromatin coils become more obviously ordered and the star-shaped

centres grow larger and send out more radiating spokes, and the boundaries of the nucleus fade away. The radiating spokes appear to be lines of stress along which the chromatin strings, doubled in number by

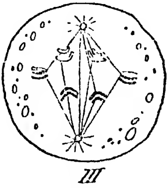


FIG. 78.

splitting, are divided into two even-numbered sets, one set proceeding to one end of the cell and the other set to the other end. The chromatin strings now have very definite figures and are called chromosomes. The star-shaped centres move to opposite sides of the cell and the chromosomes assume a very regular position

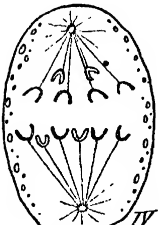


FIG. 79.

across the diameter. They are seen to be in similar pairs, as would be expected, for they arose from the longitudinal splitting of the chromatin string. In the next stage the whole cell noticeably elongates and one

set of chromosomes seems to be drawn towards one star-shaped body and the other set to the other star-shaped body. The cell elongates until a neck appears in the middle, and the chromosomes gather together

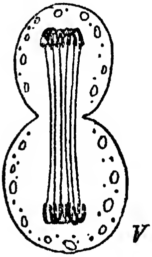


FIG. 80.

into clumps on the site of the star-shaped objects. The neck narrows until the two bell-ends break asunder, the lines joining the two sets of chromosomes disappear

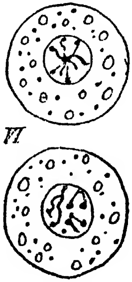


FIG. 81.

and there is a rapid readjustment of the contents as the broken ends concentrate themselves into separate cells. The chromosomes seem to be broken up into the scattered stringy form in the nuclei of the new cells,

and cell growth proceeds until each cell is ready to multiply as its parent did.

Why cells should multiply in this complicated manner is at present obscure. Possibly the mechanism is one of specialisation. Since the nucleus or its equivalent is the most permanent feature of cells, its contents are probably the most vital. These are the entities possessing the fundamental properties of growth and reproduction, while the rest of the cell is a convenient auxiliary mechanism. If the nuclear contents, in particular the chromatin granules or chromosomes, had to engage in growth and reproduction simultaneously, the chance of their developing their potentialities would be less than if they could spend a period on the activities of growth, and then suspend growth for a short time and devote the whole of their energy to reproduction. The good manager thinks intensively of the job before him and make a decision on it before considering the next job. If he tries to think of all his jobs at once, he becomes muddled and none is done satisfactorily.

Observation shows that the number of chromosomes appearing in the cells of a particular species is even and constant. If the cell is taken from man, the number is seen to be 48. A certain crayfish is said to have 200, and one species of water-flea has 4.

In the process of division the chromatin in the nucleus is formed into a string which splits into pairs of chromosomes and one of each pair is taken to help in the making of the two new nuclei. Evidently the constancy of the number and selection of the chromosomes is important. The chromosomes themselves are not all alike, some are bent, others like rods and others particulate; yet in division each new nucleus contains just one specimen similar to each of the kinds found in the parent nucleus. Since there is such careful ritual in arranging that all cells have the same even number and

combination of chromosomes, it is not unreasonable to suppose the chromosomes have something to do with the preservation of the cell-type and are a part or the kernel of the controlling mechanism which makes all cells retain the characters of their parents, and prevents the cells in a man suddenly generating cells like those in a crab or a tree.

Cells living independently merely increase their number when they reproduce. If they have the ability of sticking together, surprising things may happen. Even non-living things which stick together produce remarkable appearances when made to reproduce by

FIG. 82.

external agency. A thin strip of paper as in (*a*) is twisted once and the ends stick together as in (*b*). If the ring (*b*) is slit into two down the centre of the strip with a pair of scissors, two intersecting rings are produced. If the rings in (*c*) are both slit again, a group of four inter-locked rings is formed. More slitting produces a quite complicated system of rings. So even with a mere strip of paper reproduction by splitting may make a complicated structure.

Among the thousands of different kinds of cells there are eggs; hen-eggs, frog eggs, crocodile eggs, human eggs. Eggs have only one nucleus, but may have a relatively enormous quantity of yolk and white of egg surrounding it. The chief bulk of an egg is a non-living store of food for the nuclear cell and the products of its generation to draw upon (see Plate XXII). When the cell splits and multiplies its progeny are surrounded by food. This is why eggs are so nourishing. Nature

evolved them as food-providers for the little nucleus within. Man rifles this natural store of food prepared according to the best natural recipe.

The start of the growth of eggs has some preliminaries which will be described presently. But once cell-division has started, the process in the early stages continues in a manner common to most organisms. The cell splits into two. Then into four. Then into eight, sixteen, etc. In the first three stages the structure is solid, for two, four and eight cells combine into solid figures; the eight cells making a cube. In the fourth stage the sixteen cells are arranged cylindrically; the organism already shows a simple inside. At the next sub-division the thirty-two cells form a sphere. At the next, there are sixty-four cells arranged over a sphere containing fluid.

In *Amphioxus* the development in eleven subdivisions is seen in Plate XXIII. The bending-in of the cells on one side of the sphere is commencing in the seventh stage, and in the tenth the differentiation of the cells into two layers, one external and protective and the other internal and digestive, is clearly seen.

A similar course is seen in the early divisions of a frog-egg. The cells subdivide until there is a continuous spherical layer. Then some cells increase their rate of growth and cause the crumpling so that the organism has an inner and outer layer of cells. A third layer of cells divides off between these layers. So in the frog the rudiments of the skin, sense-organs and nerves are found at this early stage in the outer cell layer; the middle layer are the forerunners of the muscle, skeleton, blood, kidney and reproductive organs, and the inner layer contains the rudimentary lining of gut, liver, lungs, etc.

At this stage the future organs of the animal begin to differentiate visibly. A groove appears in the back, deepens and curls over to form a tube which becomes

the spinal cord and brain. On the head rudimentary eyes, ears and nose appear. On each side of the gut sets of rudimentary muscles for operating the future limbs develop.

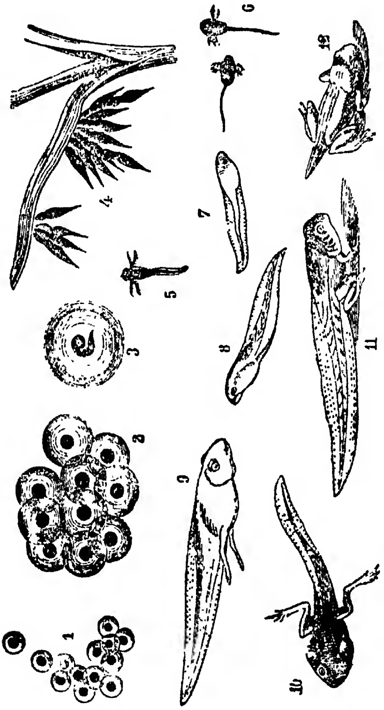


Fig. 83. Stages in the Development of the Frog. (After Marshall and Brehm.)

Rudimentary kidneys and excretory organs develop out of a cavity in the middle layer of cells. The mouth

and arms and gill slits begin to form and tubes of cells to become rudimentary blood-vessels. This rapid evolution from the simple layered embryo to one with obvious rudimentary organs happens in not more than forty-eight hours. Though the embryo frog has developed rudimentary organs these are as yet only protoplasmic moulds or scaffoldings. The figures looking like future eyes, kidneys, livers, guts, etc., are not living as organs but merely as collections of individual cells. These cells have been concerned in the production of organ-like structures, as Pygmalion sculptured the statue but the material of these structures has not assumed the life of the organ, as Pygmalion's marble had not assumed the processes of life. The cells at this stage are suited only for rapid division and brick-like building up of form. They are not suited in their various sites in the liver, for example, to produce the digestive juices. The cells in the various parts of the body have now to adapt the customs of local inhabitants, and change from their uniform brick-like character into cells respectively suitable for liver, brain, muscle, gut, etc.

When this change is accomplished all the cells in the body are more or less ready to work in their appropriate manner, so the organism is ready to be hatched. It is now a tadpole able to make its own living. The habit of self-feeding and use of its body engenders a further stage of development. At the end of this, the animal is ready to make a final change from tadpole into a young frog. In this sudden change lungs and head and legs develop, the colour of the skin changes, and the internal organs. The intestine shortens from one suitable for vegetable, and becomes suited to the digestion of animal food. The tail and gills of the tadpole are actually reabsorbed back into the animal by the action of wandering cells and their material used in the construction of new tissue (fig. 83).

The young frog goes on growing, until transformed from a juvenile into an adult. Adolescence is its next crisis, after which its sexual cells mature and it is prepared to achieve the full frog life. For a comparatively long period there are no more great changes, the animal having settled down to a steady rhythm of existence. Finally the pulse of the rhythm declines, tissues lose their vitality and age sucks out the sap. The animal becomes feeble and a prey to enemies and is killed. In an aquarium it might perhaps decline, worn out, into death, but in the world its end almost certainly would be violent.

Organs develop from specialisation of cells. Some cells specialise in digestive processes and make guts and stomachs, others as sensory organs in the eye and connected with the brain, others in nervous systems and musculatures. Cell specialisation occurs also in reproduction. The initiation of these processes is left to the cells in special organs.

In the female frog the ovaries contain cell-eggs from which frogs can develop. If some of these eggs are taken out or collected when ejected from the animal, they can be caused, by a skilful technique, to commence subdividing and building up a new animal according to the scheme just described. The eggs have to be pricked with a fine needle dipped in blood. Starfish eggs can be started on their career of subdivision by heat, and sea-urchin eggs by chemical treatment. These discoveries are very interesting and show that sex is not fundamental to reproduction even in highly organised animals. Perhaps biologists will discover one day how to make the male reproductive cells of frogs subdivide and produce normal frogs by some kind of chemical or physical treatment, though this is doubtful. The problem is difficult because male reproductive cells, the sperm, are exceedingly small and delicate, consisting mainly of a nucleus and a fine thread. The experimenter trying to

make sperm subdivide would have to provide them with a store of food artificially. Female eggs have yolks naturally provided for the purpose.

Since sex is not theoretically necessary for reproduction, a modern scientific discovery very surprising to everyone, why has sex come to be so involved in reproduction? It must be a refinement to obtain subtler

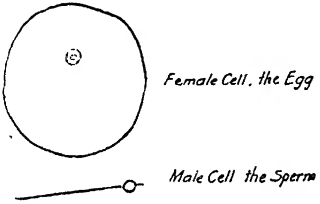


FIG. 84.

results. At some stage in evolution after the primitive cells in a simple organism had already developed a specialisation in reproductive processes, there must have been a further specialist subdivision. The group of reproductive cells divided into two sorts, one concerned with the accumulation of food to assist subdivision, the other concentrating on vital accomplishment, the achievement of powers of swift movement and activity. In this early organism the reproductive cells began to diverge into two types, one large, quiescent, full of food material, the other small and active and accomplished. When new organisms had to be produced, both sets of specialised cells were ejected and expected to collaborate in the reproduction, the egg-cells providing the conservative, the sperm-cells the initiative characteristics, required in combination in the most desirable organism. If there had not have been specialisation by the reproductive cells, they would not have been able in themselves as one

uniform type to evolve together the characters of large food-storage and activity to such a high degree as separately. Here perhaps is one of the explanations of the origin of sex. Some organisms have not evolved beyond the stage of specialisation of reproductive cells within themselves. They have not advanced to the stage of evolving different kinds of mature organisms to bear the different kinds of reproductive cells, and have no differentiation into male and female.

An organism reproducing by simple subdivision and having no relation with other members of its race has only its own heritage to draw upon. The range of possibilities in its offspring are very small and it cannot benefit from the qualities of others.

If any of its colleagues have specially admirable characters it has no mechanism for arranging that some of them should appear in its offspring. Clearly it is desirable different members of a race should be able to exchange some of their qualities so that as large a range of characters as possible should be tried in the racial life. The greater the variety tried by the experience of life the better chance of discovering the best racial type. This is accomplished in simple single-celled organisms by an extremely interesting mixing process quite different from reproduction.

Two cells approach, merge together, mix themselves up and separate again. The two resulting cells have bits of the others in each of them. There is no increase in the numbers of cells through this mixing process, it is not reproductive. But the two new cells seem to be more vigorous than the two old ones, they seem to be stimulated by the re-assortment of their sum of characters. This re-assorting activity and not reproduction seems to be the true function of sex. In the higher animals both mixing and reproduction happen together and until the process was carefully analysed by modern biologists, the

object of sex was naturally supposed to be purely reproductive. This apparently is not so. Sex has to do fundamentally with vital refreshment and exchange of potentialities. Two organisms uniting sexually are fundamentally trying to obtain new living possibilities. Reproduction is quite another activity and has been combined with sex in higher animals for convenience and efficiency, just as some of the same organs are used for the quite different purpose of excretion. It should

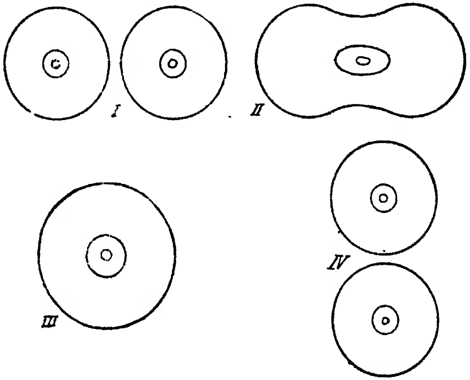


FIG. 85.

be realised that in the last analysis the three activities of reproduction, sex and excretion are fundamentally distinct. In her tendency to mechanical economy nature has arranged to use some organs for all of these purposes, to the serious confusion of philosophers.

Some thinkers approaching life from aspects other than the physiological have discovered this truth for themselves with various degrees of clarity. Perhaps this was the discovery D. H. Lawrence had made by profound

plumbing of the human consciousness. His passionate exhortations on the importance and inspiration of sex were due to his apprehension of its power of vital renewal. I consider his contention is supported by modern knowledge of the physiology of sex, and the phenomenon of the appearance of the same idea at the same time in two different regions of human thought is of considerable interest to those who assert that ideas are manufactured out of the environment of their day, and do not spring up at the whim of providence. Perhaps this is one of the explanations of the deep feeling that in spite of his limitations D. H. Lawrence is one of the few recent English literary workers of solid creative genius.

XXX

FERTILIZATION

Nature has evolved a specialisation in the technique of reproduction in the higher organisms. She has exploited sex to assist in the process and arranged that there should be two types of any organism, one to bear reproductive cells specialising in food storage and the other in physical activity. She has also had to arrange that these two types of cells must combine and share their potentialities, if organisms with new assortments of potentialities are to be produced.

At first sight, there seems to be no reason why the two types of cells should not just combine into one, and then the organism could evolve from this new unit by the ordinary method of cell division.

This would not do, however, for this cell would contain double complete sets of potentialities. It would have too much. Its descendants would have four times as many, and so on. A process is necessary to halve the potentialities in reproductive cells in organisms of each

sex, so that when they combine and exchange their assortment of potentialities, the two half-sets will together make up a normal complete set.

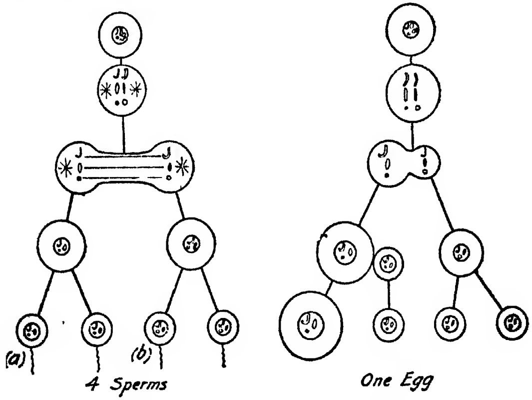
Accordingly in organisms using sexual reproduction there is still another stage of evolution in their development. After cells have begun to specialise for reproduction and consequently differ from cells beginning to specialise in digestion, etc., they specialise once again at a late stage. They split into cells with only half the normal number of potentialities. This is the explanation of the origin of the even number of chromosomes generally found in cells. Since any cell is ultimately an offspring of male and female ancestors it must have a set of potentialities from each parent, so it has one chromosome of each type from each parent, i.e., it has two chomosomes of each type for its normal complement, making an even-numbered set. The normal complement of potentialities is contained in an even-numbered set of pairs of chromosomes.

In the reproduction cells of males this further stage of development is represented in fig. 86 (I), and for females in (II).

The immature male reproductive cells subdivide into four sperms, the nucleus of each containing only half of the chromosomes in the normal cells for the rest of the organism's body. The immature female cells subdivide in four, one of which is much larger than the others, and it is the only one to survive, the three small cells (called polar bodies) subsequently disappearing and being destroyed.

It is interesting to notice that in general the selections of chromosomes in two of the sperms differ from that in the other pair. This means that the potentialities of the sperms are different, and among possibilities, the sperm will be either female or male in its potentiality. Similarly the egg from the female reproductive cells

may have either of two potentialities. Hence there are four different kinds of special cells concerned in sexual reproduction, male organisms containing sperm with female potentialities, and female organisms producing eggs with two sets of potentialities, though these do not include sex. A curious deduction can be made from these facts. If the egg-cells of women could be caused to develop by artificial means, as the eggs of frogs are by pricking with a needle dipped in blood, the human race could be restricted to women and yet survive. Theoretically



(I) FIG. 86. (II)

boys would be produced by these abnormal artificial fertilisations, but there would probably be a few girls, as the experiments with frogs show a small percentage of females.

Since one-half of the sperms in men are female-making and the other half male-making, the number of boys and girls brought into the world are approximately equal.

Suppose the sperm nucleus labelled (*a*) in fig. 87 fertilises the egg. The sperm penetrates the egg, adds

its quota of chromosomes, and then the egg divides. Suppose, however, that sperm nucleus (*b*) in fig. 88 fertilises the egg.

It is seen that the developing egg which will produce an organism eventually, has a different complement of chromosomes. For instance, in the first case, with sperm (*a*), the resulting developing cell has two black dot chromosomes. In the second the cell has one black and one white dot chromosome. All its descendants will have the same complement. It is natural to wonder whether the characteristic differences of the mature animal resulting from these different sets of chromosomes may not contain the factors controlling heredity. Besides appearing always in constant numbers in the cells of any species, they are almost the only part of the organism which has the potentiality of eternal life. By the splitting in the subdivision of the nucleus in cell-division the contents of the chromosomes persist and their offspring pass on to other organisms. The chromosomes in an animal's reproductive cells hand on parts of themselves in the animal's children. They are not mortal like the rest of the animal's body. The potential eternity of existence and the extreme orderliness of chromosome arrangements in cell-division suggest strongly that they contain the factors governing inheritance in organisms. Biologists have therefore most carefully attempted to correlate characters of organisms with the chromosome equipment of their cells. They have looked to find whether monstrous animals have peculiarities in their chromosomes, and whether the characters of an animal could be deduced from its chromosomes. If someone sent them a piece of tissue from a fruit-fly and some information about its ancestry, could they by studying the chromosomes in the cells of the tissue deduce that the fly would have certain characters, and then write to their correspondent asking him

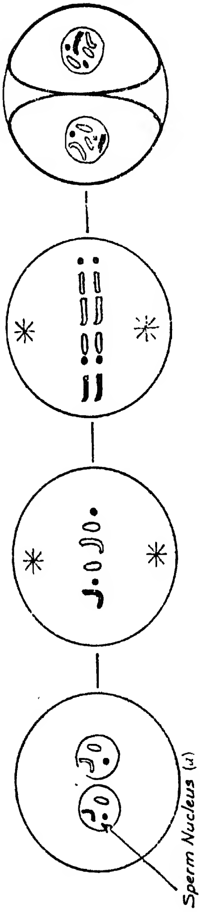


FIG. 87.

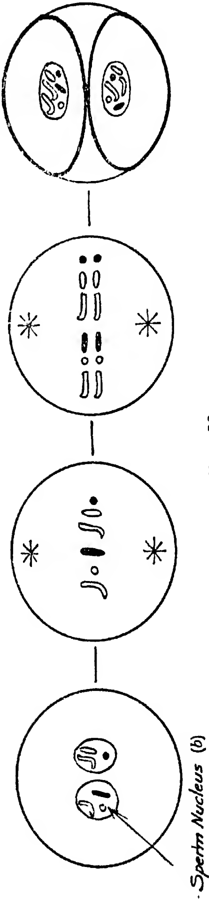


FIG. 88.

to look for these characters in the fly, and then hear that he had found them? Feats of this kind have been achieved, so there is strong evidence that hereditary characteristics in an organism are determined by the nature of its chromosomes.

In the beginning there was space-time. This differentiated into protons and electrons. These combined together to form atoms. Atoms combined to form chemical compounds. Chemical compounds combined to make colloids. Colloids combined into complicated self-reproducing substances, and these evolved at first probably just by themselves. Later mixtures of them accumulated and reproduced mixtures rather than individual substances, like very simple bacteria. Presently the mixtures congealed or differentiated into groups which now began to develop their own complicated properties. These groups became visible as granules and accumulated a coat of fluids around them so that they appeared as structures in the nuclei of cells, and these structures are called chromosomes. But chromosomes have a constitution and an evolutionary history and are built up of many different, more elementary self-producing substances. Though these, like electrons and atoms, have never been seen, there is strong evidence for their existence, and they are called genes. We suppose, therefore, that chromosomes are made up of many different kinds of self-reproducing substances of constant composition called genes.

XXXI

HEREDITY

When frog's eggs are launched on their career of development not by fertilisation with male sperms, but by pricking with a blooded needle, they may develop into

normal frogs. The cells of these frogs contain the normal number of chromosomes, yet the eggs they developed from contained only half the normal number.

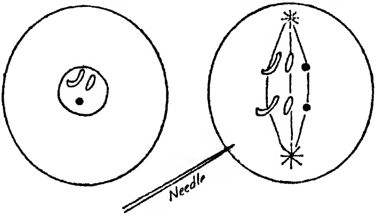


FIG. 89.

Suppose an animal-egg being artificially activated contains three chromosomes, half of the normal number six. When pricked, the cell commences to subdivide, but does not complete the process. Instead of the two sets of three chromosomes grouping together into two nuclei, the process is arrested and the six chromosomes group together into one nucleus. Afterwards the process of subdivision continues in a normal manner and produces a normal animal (fig. 90).

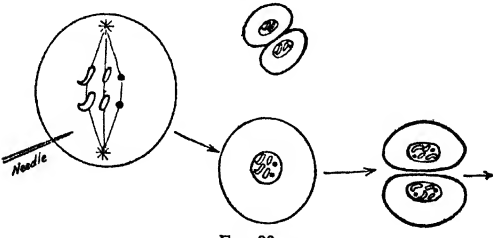


FIG. 90.

Artificial fertilisation by needles, chemicals, heat, etc., produces organisms of both sexes, but mainly males (Plate XIXb).

How is the sex of an animal usually determined? By the nature of those chromosomes containing the gene relating to sex.

Fig. 91 represents the nucleus of an immature reproductive cell from a male animal, such as the fruit-fly or man, showing only those two chromosomes containing sex genes. One chromosome was derived from its

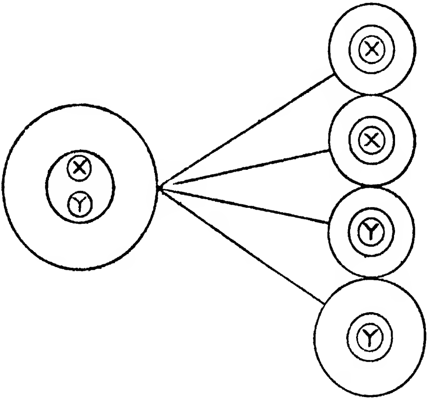


FIG. 91.

mother and is female-determining (X), the other from its father (Y) is male-determining. It subdivides into four sperms each containing one sex chromosome, so two sperms will have X only and two Y only. The immature female reproductive cell nucleus contains an X-chromosome derived from its mother, but instead of deriving a Y-chromosome from its father it received one of the X-chromosomes, thus the female egg has two X-chromosomes and cannot avoid being entirely female (fig. 92).

Since certain chromosomes contain the gene determining whether a cell shall be male or female, and probably contain genes determining other characters also, we may expect to find sex and these characters determined together.

It appears that certain kinds of colour-blindness in man are controlled by a gene in the sex chromosomes.

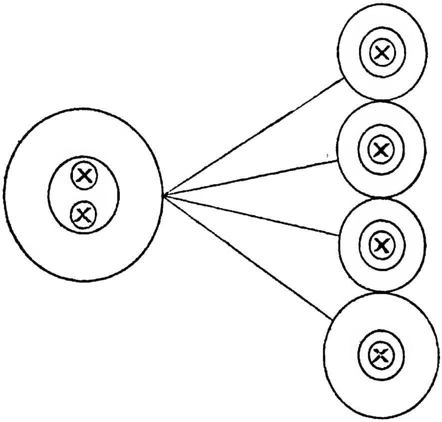


FIG. 92.

Consequently, the transmission of the character to the descendants depends on their sex. A colour-blind man with a normally-sighted wife has normally-sighted children, but one out of every four grandchildren is both male and colour-blind. The colour-blind descendants are always male.

The chromosome distribution which causes these effects is given in fig. 93.

Examining this diagram, it is seen that the colour-blindness gene is in the daughter cell on the left, yet colour-blindness does not appear in the daughter. The gene is there but not active. In the son-cell on the right the colour-blindness gene is not there. Evidently genes are sometimes active or sometimes passive, dominant or recessive.

The cell in fig. 94 has six chromosomes, two of each kind. Suppose the black dot chromosome came from the father, the white dot from the mother, and that

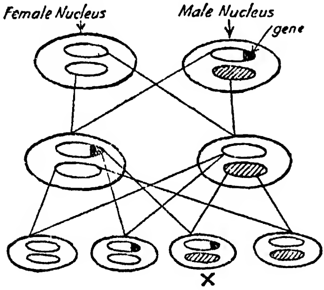


FIG. 93.

genes in these chromosomes are responsible for the colour of the animal's hair. If the father was red-haired the gene for red-hairiness must be in the black dot, and if the mother was fair-haired the gene for fair-hairiness must be in the white dot. Now the genes in the cells must either act together, or separately, the animal must have hair of a mixed colour, or red or fair. Some of the offspring are often found to have either red hair or fair hair, but never a mixture. If that is so, one gene must be able to exert its effect always, while the other can do so only when the former is absent.

Suppose a gene is dominant; if it is in all of its parents' appropriate chromosomes, all the descendants will contain the gene and have one of their characters governed by it. This condition is represented in fig. 95a, and results in a pure breed for this character. Entirely red-haired cows when pure-bred for redness will produce red-haired calves and descendants only.

Suppose one parent has a dominant gene for one character and the other has not. In the first generation all the offspring have this character. With random mating in the second generation three out of every four, and in the third nineteen out of every twenty-four.

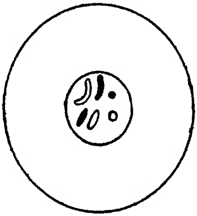


FIG. 94.

Conversely, if a gene is recessive, it will appear in a random mating only once out of four times in the second generation and not at all in the first. In the third generation it will appear only five times out of twenty-four. Yet the recessive gene will be in the cells of all the first generation in three out of four in the second and in nineteen out of twenty-four in the third.

Suppose a man has a recessive gene for insanity and he marries a normal wife. His children will all be sane. With brother-sister mating, one out of four of his grandchildren will tend to be insane, and five out of twenty-four of his great-grandchildren, and fourteen others will have the power of transmitting insanity.

Only five will be entirely free of insanity, though with conventional mating the figure will be much higher.

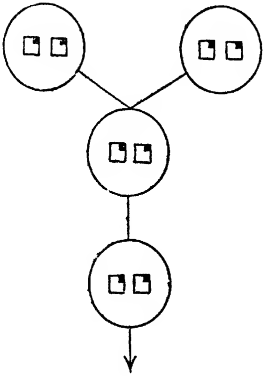


FIG. 95a.

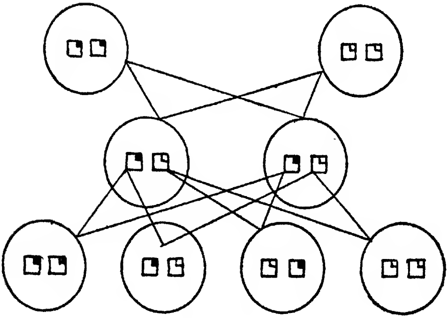


FIG. 95b.

Chromosomes contain groups of genes and hence the determinations of groups of characters. If the processes of cell division were always performed by nature perfectly exactly, only groups and not individual characters could be transmitted. For instance, if the square-head gene and the red-hair gene were in the same chromosome, animals containing this chromosome in their cell would be both square-headed and red-haired, but never square-headed and black-haired, or red-haired and round-headed. But the cell divisions are not always performed exactly. When a reproductive cell is ripening the chromosomes sort themselves out in pairs.

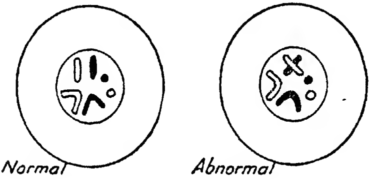


FIG. 96.

Sometimes they become entangled and crossed. When the cell subdivision occurs the crossed chromosomes break and the parts go off with the wrong partner. If this happens, genes which used to be in one chromosome have been transferred to its companion. The cell does not contain less genes, but they are in different groups. The genes can be interchanged to some extent between companion chromosomes.

Though this process is very difficult to establish by microscopical study and the direct evidence for it is meagre, the indirect evidence is striking.

It is possible to obtain specimens of the fruit-fly (*Drosophila*) with black bodies and short wings. The genes for these characters lie in a certain chromosome

When one of these flies is crossed to a normal fly with normal colour and wings the offspring appear normal because the black body and short wing characters are recessive. If one of the female offspring is mated with a black male, the next generation are of four kinds. One is like the normal grandparent, the next is like the abnormal grandparent and the third has normal long wings but black body and the fourth normal body but vestigial wings. The chromosome movements are given in fig. 98.

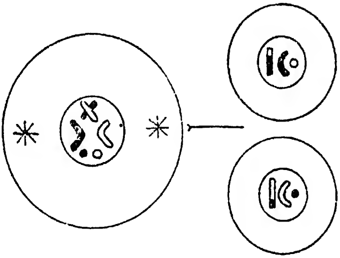


FIG. 97.

The phenomenon of crossing-over in *Drosophila* has been exploited most ingeniously by T. H. Morgan and his school for locating the actual position of genes in chromosomes. Suppose two genes are situated at the position marked into the two long chromosomes in the figure. In the accidental twisting of these two long chromosomes at the ripening cell subdivision they may become twisted with equal probability at any place along their length. The twists might be at any of the following places, for example. The chances of a twist falling between genes in a chromosome clearly depend on the distance between the genes. If they are at opposite ends of the chromosome every twist and breakage will

separate them. If they are close together few twists will separate them. The chances of a separation will depend on the ratio of the length of the remainder of the chromosome to the distance between the genes.

For the chromosomes in figure 101, the ratio will

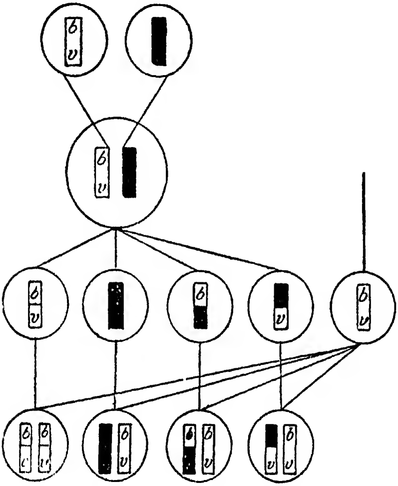


FIG. 98.

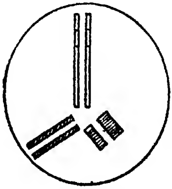


FIG. 99.

be a/b. By observing the percentage rate at which exchange of characters normally linked together occurs, it is possible to deduce the distance between their genes in the chromosome carrying them. By deducing the

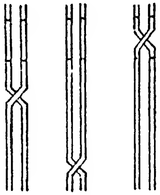


FIG. 100.

distances between other pairs of genes, one of which was in the previous pair, it is possible to make a map of gene-distribution in the chromosome. The method of the process resembles rather that of stereochemistry, where the relative position of atoms in chemical compounds is determined from the nature of the compound's

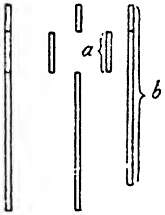


FIG. 101.

reactions with other chemical substances. The deductions of stereochemistry have been confirmed in recent years by X-ray analysis. Photographs have shown directly that the chemist's deductions were correct.

Perhaps some kind of X-ray method will one day directly expose the position of genes in chromosomes.

The twisting and breaking of companion chromosomes in the subdivision of ripening reproductive cells produces a numerical distribution of characters which can be observed in animals such as the fruit-fly. More serious accidents in cell subdivision cause stranger effects in the animal resulting from the development of the cell.

In fig. 102 one of the chromosomes has split and then stuck together again. After the division one cell has

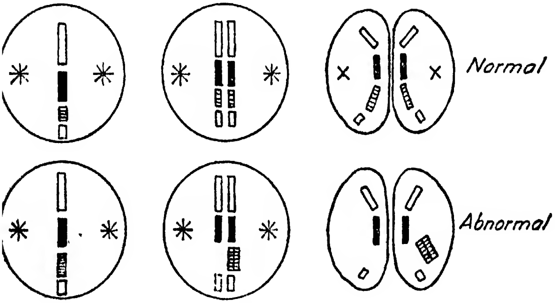


FIG. 102.

only three chromosomes and the other four, one being of double size and bearing double its usual number of genes. The organism from the second cell could mate with the normal organism because the number of chromosomes would be equal, but the offspring would be abnormal because of the new double-sized chromosome in its cells.

Less simple than accidents to whole chromosomes, there may be slight accidents, such as a bit of one chromosome sticking to another, or one breaking up

into parts and starting a race with more than the usual number of chromosomes.

Then sometimes a reproductive cell subdivides and the nuclei recombine and form a cell with double the usual number of chromosomes. Triple or quadruple sets are possible. If the cells reproduce successfully after the accident a new stable race of organisms arise. Accidental chromosome complications of these kinds are usually fatal to animal reproductive cells, throwing these complicated reactions out of gear, but plants often withstand them successfully. For instance, with plant-cells chromosomes from different species of plants can be obtained. Certain roses have five different species of plant chromosomes in their cells. It is possible to obtain a plant with turnip, cabbage and radish chromosomes in its cells. The plant is perfectly stable and its offspring resemble itself. Several of the new commercial varieties of fruit and vegetables have arisen thus accidentally through mixing up of genes.

Though these changes in distribution of genes, and even of chromosomes from different organisms, are known, the cause of the accidents producing them is not understood.

XXXII

MUTATIONS

Genes are made out of self-reproducing chemical substances. Under suitable conditions they normally live for ever unchanged, but sometimes their chemical constitution may be altered by a physical accident. A chemical or physical force in the environment may cause an alteration in their chemical constitution, or some fundamental internal instability resembling radioactivity, which acts from time to time and causes a spontaneous rearrangement of the atoms in the gene,

until an external force or the next radio-active-like explosion causes yet another rearrangement.

Changes of this type produce genes possibly different from any other previously existing genes. Such new genes may exert an influence on the organisms containing them in their cells different from that exerted by all previous genes; the organism shows a new character.

These changes are continually happening in nature. A pure race of organisms, all of whose genes are known, reproduces itself perfectly for a greater or smaller number of generations, and then suddenly throws a new offspring having characters different from any before seen in the race. This is due, according to the gene theory of heredity, to a sudden change in the chemical or structural constitution of one or more of the genes.

The effects of the process are observed beautifully in Johannsen's experiments with garden beans. These plants multiply by self-fertilisation, so no gene goes into the gene-equipment of descendants which was not in the parent bean. Johannsen kept the seeds of each plant separate. He found that the plants from these seeds produced crops of beans with a definite range of size. The average size of the beans from the smallest seed of the parent-bean was just the same as the average size of the beans from the largest seed. Also, the range of size of the descendants included the size of the parent-bean. What do these results mean? That there is a fixed factor in the beans which tends to keep them to a certain size. How then do the variations in size arise? These must be due to accidental environmental circumstances. If the bean grew in the corner of a pod, or on a feeble branch of the plant, or on poor or rich soil, or was exposed to especially good or bad climatic conditions the tendency to grow to a certain size would be stimulated or inhibited. The variation in size must be due to accidental causes arising during lifetime. The

very important principle emerges that small variations in a race are due to environment, but these variations arise only during lifetime and have no effect on the descendant of the organisms showing them. The factor, the gene, which determines the tendency to grow to a certain size, is not affected by environment because the descendants of beans which had the most varying environmental life still carry the same tendency to grow to a particular size. If a seed from the parent-bean whose descendants we have been discussing were planted in stony soil cut off from sunshine by a wall, its descendants would be puny. But these puny seeds would give beans of the normal size if set in a normal environment.

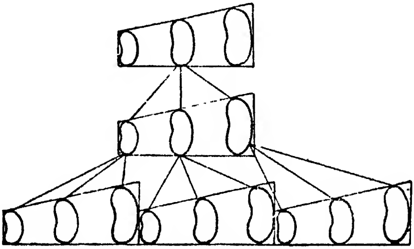


FIG. 103.

The offspring from one bean can be cultivated for many generations, and each generation be grown in a different environment, yet the seeds from the last generation will have the same tendency as those from the first to grow to a certain size. The gene for size remains constant and is passed on unchanged in constitution from generation to generation.

The stability of the gene is remarkable; nevertheless, it is not absolute. Johannsen found that though a pure line of beans kept to the same average size for many

generations, now and again a tendency to grow to another average size appeared suddenly. It was found that the seeds of a descendant of the original bean were not of the average size, but of a new average size. Now the descendants of this crop of seeds preserved the new average for many subsequent generations. Evidently there was a sudden change in the constitution of the gene of these seeds and it set a new fashion in sizes for its descendants. These sudden changes of hereditary tendency after many generations of extremely stable breeding have often been recorded. There is the case of the Ancon sheep mentioned by Darwin. A lamb was found to mature into a peculiar ram with short legs and long back. Its characters proved to be stable and were inherited by its descendants. The herd of short-legged sheep had a special value since its members could not jump over hedges and consequently required less attention. The British bulldog is said to be a descendant of a peculiar dog thrown by a mastiff.

Sudden changes of this kind have been repeatedly observed in animals and plants living under wild and domesticated conditions. They are easier to observe under carefully controlled laboratory conditions. For instance, the water-flea (*Daphnia*) was bred for 363 generations and preserved unchanged its character of thriving best at a temperature of 20° C. After fourteen years' steady breeding, a strain appeared suddenly whose optimum thriving temperature was 27° C. A tobacco plant of Northern U.S.A. suddenly produced offspring which would not flower and seed. Experiment showed it would flower if treated with artificial light so that its day resembled that of the sub-tropics instead of Northern U.S.A., a new kind of sub-tropical tobacco plant being discovered for commercial exploitation.

In the fruit-fly, Morgan and his school have noted 400 sudden changes in characters, some large and

others slight. The fruit-fly with black body and vestigial wings bears a gene for these characters which arose suddenly. It produces an extraordinary change in the appearance of flies bearing it. Other fruit-fly gene mutations are much less drastic in their effects on their bearers, and may cause a slight change only in the colour of the eye and wings.

All these sudden changes in inheritable characters so far mentioned have been observed to arise apparently by change in organisms growing wild or under domestication.

Very recently biologists have succeeded in making genes change or mutate by application of chemical and physical agents. Harrison fed certain moths with food soaked in weak solutions of manganese and other metallic salts. These affected the pigmentary gene, causing it to change and become a determiner of blackness. The changed gene was inherited stably by descendants who bore the black character without themselves being given manganese meals.

Harrison was led to this experiment from a consideration of the appearance and distribution of certain black or black-marked moths in the industrial districts of Britain. For instance, in 1898 no dark specimens of the moth *Ypsipetes trifasciata* had been found in North Durham. By 1910, light specimens were difficult to find. Similar phenomena were observed in other countries where industrialism had been developed, such as Germany, Belgium, France and U.S.A. Harrison suspected the deposits of chemicals from industrial smoke on the vegetation in the moth's environment had affected their sources of food and caused their colour-gene to change. His feeding experiments in the laboratory strongly corroborated his suspicion.

H. J. Muller of Texas has shown that X-rays or similar rays from radium can have the effect of changing the constitution of genes in fruit-flies. After X-rays had

been discovered, the lethal powers of strong doses were soon demonstrated. They were found to sterilise reproductive cells when in sufficient strength. This property has made them useful for the treatment of various tumours and infections in the body. By careful regulation of the strength of the dose, Muller found the reproductive cells of the fruit-fly could be affected without serious damage to their fertility.

The sperm cells of the male could be rayed before the sperm had been transmitted to the female, or rayed when already in the female, and fundamental changes in the genes be induced. The treatment of unfertilised females was also effective. The changes in characters due to these gene changes were of every type, some being so fundamental that the organism could not live, others were physiological, and others were indistinguishable from the changes seen to have occurred in natural mutations when the organism was not subjected to any abnormal influence.

Muller's experiment is extraordinarily interesting. It means that man can produce races of organisms with entirely new characters, and is not necessarily forced to wait upon caprices of nature for the appearance of new varieties of organisms. Until now he has been able only to take care not to miss the useful new organisms mutated by nature. He could not be more than a careful husbandman. Now he is partly master, though not wholly, for he can make changes only, not changes in what he considers are desirable directions. In fact, most of the changes produced in the flies are in the wrong direction. At present he can proceed to produce new types, and knows when he X-rays organisms suitably he will get new types, but he is not yet able to foresee and choose the type. Already new varieties of corn and other plants have been made by X-ray treatment in the hope that new improved stocks will appear.

The next step is to discover how to direct the change, not produce a mere change, but a change in the desirable direction. When that is discovered man will become a master of evolution and will not only guide his own life, but produce new life-possibilities, men with powerfuller bodies and finer minds who perhaps will accelerate enormously these first advances towards the human control of evolutionary destiny.

Muller's achievement has suggested another remarkable speculation. X-rays, rays of short wavelength, do exist freely in the world and arise from several sources. Many radio-active substances emit very short-lengthed X-rays. Possibly the radio-active materials scattered through the earth are continually affecting mutations in living organisms. Then lightning flashes cause electrons to travel with enormous velocities. When the electrons strike metallic objects X-rays are produced. More thrilling than those, there are the cosmic rays. These come from outer space, have great penetrating power and considerable intensity. The total energy of the cosmic rays reaching the earth is comparable with the total energy of the starlight received by the earth. There is the possibility that the new characters and hence all except perhaps a few primitive characters in living organisms are due to rays arriving at the earth from outer space. Later experiments by workers of Muller's school appear to show, however, that mutations occur too quickly to be due to cosmic rays only. There must be other causes.

After discussing the causation of mutations it is natural to enquire of their frequency. How rapidly do fundamental changes in the determiners of characteristics occur ? In the fruit-fly 400 changes in the constitution of genes are known. This number is very large, but still is probably only a small fraction of all the genes in the fruit-fly. In nature there is an immensely greater

number of flies than in laboratory experiments, so presumably the number of gene-changes which have occurred in nature during the period of laboratory experimentation is vastly greater. Zeleny has found that, on the average, a hundred thousand fruit-flies show 28 to 61 gene-changes. It is estimated that a thousand years of breeding would be required to change every gene in this organism, and the mutation rate in the fruit-fly is enormously quicker than is known in any other organism.

Muller has speeded up the rate of mutation in fruit-flies 150 times in his X-ray experiments. Hence he can produce artificially mutations at the rate of 4,200 to 9,150 per 100,000 fruit-flies, and could expect to change every gene in the fruit-fly in about six years.

XXXIII

EVOLUTION OF LIVING ORGANISMS

KNOWLEDGE proceeds from the outside inside. Historically the atom, the electron, the gene are deductions from external phenomena. The early Greek philosophers postulated atoms because they wanted an entity capable of showing both the stability and the flux of the objects of primitive perception such as water, air, fire, earth and living organisms. These things are continually changing and yet always exhibiting certain constant qualities. If they were made of collections of very small particles of constant properties their two qualities would be explained. After centuries of study this speculation has been more and more substantiated. Besides the constant recurrence of the same qualities in things, quantitative constancies were discovered. Substances always combined together in constant quantities, indicating there was a pairing-off of entities

in them when they combined. The pressure of gases could be explained if they consisted of particles and the rate of diffusion of gaseous particles through porous plugs allowed estimations of their size and rate of movement to be made. The constant connection between the weight of substances released by fixed quantities of electricity indicated that atoms of substances could pair off with fixed quantities of electricity: electrical particles. Nothing attributable to a single particle was seen in any of these investigations. The whole atomic theory was erected on the properties of the outsides of things, containing millions of the postulated particles. Then modern atomic physics was initiated by the discovery of cathode rays consisting apparently of streams of electric particles. These produced X-rays, and X-rays could be used to release individual electric particles capable of demonstrating their presence by disturbing the movements of drops of water in clouds. About the same time, radio-active substances ejecting atomic and electric particles individually capable of registering their presence were discovered. The atomic theory received confirmation from the external manifestations of single atoms, so much more convincing than probability deductions of the existence of particles from the properties of matter in bulk.

A similar course of discovery has occurred in the study of living organisms. At first they were the objects of general observation and regarded entirely as units in themselves. Early reflection must have revealed that they were made up of various organs common to all members of a species. Then the invention of the microscope assisted: he discovery of the cell, showing that all organisms are structures of one or more cells, all of which have certain obvious general characteristics and probably an enormous number more of unobvious ones.

The external evidence indicating the existence of

units or particles of some kind having the power of determining characters in organisms was first discovered by Abbé Mendel. He showed that peas inherited many of their characters of colour and shape according to arithmetical rules. Evidently the pea contained a unit capable of conferring a certain character on itself or its descendants. The visible entity in living organisms which might contain the unit was most probably one of the chromosomes in the nuclei of cells, though this was unknown to Mendel, because chromosomes develop by splitting and run through a whole species and do not die, as the body superstructure of brain and muscle tissue dies. There may be other entities in cell-nuclei besides chromosomes which also are split and handed on indefinitely to descendants. These might possibly bear the character-determining units whose existence was suggested by Mendel's experiments, but the remarkable precision of chromosomal behaviour in cell-division suggests the units are in the chromosomes. The linkage of several characters with the behaviour of one chromosome is another strong indication that the units are in the chromosomes rather than the other nuclear substances subdivided in cell-division. Then the change of distribution of the units when chromosomes are damaged, broken or displaced strongly confirms the existence of the units of heredity, the genes in the chromosomes.

No one has seen genes. Their existence is a deduction from the external behaviour of organisms. Perhaps in the future a new technique will make their position visible, as the position of electrons has been revealed by the Wilson apparatus and the position of atoms in crystals by X-ray analysis.

The evidence for nearly all potent, simple scientific ideas is indirect. In the beginning it is almost entirely indirect and later more direct methods of demonstration are usually discovered. It is very important to remember

this when reflecting on the nature of evolution in living organisms. The simple principles, if any, which influence the life of organisms are not to be expected to be directly evident in the externals of organisms. What could appear more obvious than that the life-experience of organisms must always affect the characters of their descendants? If the organism lives in good soil or a rich environment and flourishes, having fine flowers and seeds if a plant, or brain and muscles if a man, will not its descendants tend to have fine flowers and seeds, or brains and muscles? The organism has had the experience of these good things, has learnt the trick of them, and therefore can hand on the trick to its descendants. An organism living under bad conditions has not the opportunity of learning the trick of fine development, and therefore cannot bequeath it to its descendants. This attractive theory arises at once from consideration of the externals of organisms, their relative sizes and the easy perception of the qualities of their environment. It does not, by the typical method of science, proceed from obvious external generalities to obscure but simple internal particularities. The ideological method of the theory that acquired characters can be inherited is not scientifically usual. How then do organisms evolve into more complicated forms if they do not bequeath to their descendants the lessons learnt during life? They evolve by virtue of changes in the nuclei of reproductive cells, i.e., by virtue of changes in a very small, and in complicated organisms, sheltered part of the body. Any influence which is to affect the descendants of an organism must act upon its reproductive cells.

The explanation of the failure of acquired characters to be transmitted is clear. The connection between, say, the brain or leg of an animal and the sex-glands is not sufficiently intimate for the effects of development

in brain or leg during life to be communicated to and registered in the nuclei of reproductive cells. That the connection may be there is not inconceivable since certainly brain and reproductive cell are parts in one complication of tissues, but its existence is very improbable and there is no unquestioned evidence for it.

If the germ-cells are to be affected at all by the activities of the organism they must have some channel of communication with the active parts. Since all cells in the body are nourished by food carried to them through the blood-stream, it is reasonable to expect peculiar food might reach and modify their germ-cells through the nutritive mechanism. Harrison's experiments in the effects of manganese diet on moths are a demonstration of the possibility. The food entered by the mouth and percolated through the nutritive mechanism to the germ-cells and effected in them a fundamental change.

Muller's X-rays affected the germ-cells because they have the well-known power of penetrating tissue. They could act directly on the contents of the nuclei of the reproductive cells.

We suppose, then, that changes in the characteristics of animals are due to the effects of chemical and physical forces on the composition of the genes in the chromosomes which determine these characteristics. Observation shows organisms generally tend to evolve towards greater complication, for instance a man is more complicated than an ape and a tree than a bacterium. There are exceptions, especially among parasitic organisms. These evidently had ancestors more complicated than themselves. Organisms can evolve both ways, though, usually, towards greater complication. Hence the effect of chemical and physical forces capable of changing the constitution of the gene is either to build up or break down. Sometimes these effective forces falling upon a gene complicate its constitution and

sometimes simplify it. What happens in a particular case will depend on the chemical and physical conditions obtaining at the time.

The process can be paralleled in a crude way from the facts of chemistry. When the particles shot out from radium fall upon the simple gas methane, which is a compound of carbon and hydrogen, more complicated compounds of hydrogen and carbon are produced. When the particles fall on atoms of aluminium they disintegrate some of them into simpler atoms. Whether a gene becomes more complicated or simpler and hence confers a more complicated or simpler character on its carrier appears, so far as we can see, to be purely a matter of chance, turning on whether the rare forces capable of changing the constitution happen, when they do act, to build it up or break it down. Nothing that the organism does is likely to affect the inherited character of its descendants one way or the other. In the future this may not remain true, because the experiments of Harrison and Muller show that genes can be changed by forces under our control. But even yet, the gene can only be changed in either direction; which direction is still entirely subject to chance.

By the chance action of natural forces organisms are sometimes able to confer new characteristics on their descendants. Here is the motive power behind evolution: the natural forces between substances causing them sometimes to combine into complicated compounds and at others to disintegrate. Having seen how new characters are created by the interaction of natural, that is, of chemical and physical forces, one can consider how the new characters are sorted out and what determines that organisms carrying them should flourish or decline. All organisms have to live in the world. They must collect food and guarantee their offspring a fair chance of successful life. All of them are trying to do

these things at the same time. As the world is limited in space and in its larder resources, the organisms must find themselves competing for what is going. Those with characteristics most suitable for the achievement of success in this competition will do best for themselves and their descendants. They and theirs will survive. If the chance action of chemical or physical forces should happen to change a gene and hence a characteristic of one of them, its descendants will inherit this new character. If the new character is helpful, whether in the direction of complication or simplification, to the capacity of the organism for competing with its fellows, the descendants bearing it will be favoured in the struggle for existence. As a rule, an increase in complication of character and hence of subtlety in behaviour helps most to survival, and that is why organisms tend to evolve towards more complicated types.

In the experiments on the direct changing of gene-constitution, the new characters produced all seem to be handicaps to the normal organism. So far, a new character definitely beneficial to the race of organisms experimented upon has not been proved to have been produced. This is a serious gap in the proof of the theory, but then, the technique of artificial mutation of genes is only a year or two old. In the future the technique may be improved so that definitely advantageous characters can be induced in races of all organisms, including man. Once the fine new characters are generated, natural selection will guarantee that they become dominant and gradually eliminate the older and less suitable types.

Evolution may be conceived as the history of matter whose chemical and physical properties compel it to combine into complicated forms. In the process of time, the matter becomes sufficiently complicated to

be able to reproduce itself. Then its constitution is changed occasionally by the chance action of chemical and physical forces, and it unfolds itself as organisms with definite characters which change occasionally. Natural selection determines which among the organisms is best suited to the environment and which, therefore, will become dominant.

These two principles, the tendency of matter to combine and disintegrate under the influence of chemical and physical forces; and the operation of natural selection, appear to be sufficient to account for evolution.

The first principle determines the incessant building up or dissolution of matter into new forms, the second determines which new forms shall survive. Moving according to the regulation of these principles, some of the material of the Universe has passed through the forms of simple atoms and later through the complicated forms of humanity, the primaeval stuff of the Universe has evolved from itself to man. In parts of the Universe unknown to us it may have evolved into beings surpassing man.

XXXIV

PLANTS

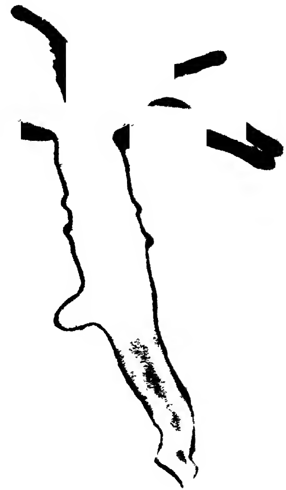
At an early stage in the evolution of organisms the two divergent methods of nutrition arose, one in the direction of improved methods of assimilation of simple chemical substances, the other in the direction of nutritive parasitism; the first method leading to the evolution of plants, the other to the evolution of animals.

A plant lives by assimilation of simple chemical substances. It usually grows in soil on the surface of the earth. The bulk of soil is a mixture of sand and stony powder and earthen dust with water, very different in nature from the material of the plant. A lettuce

appears different from soil; it is green, soft, of about the same density as water and unsatisfying as a staple diet for man. When dried it releases much water and when burnt turns black and finally leaves a little ash. These well-known facts indicate roughly that lettuces contain much water, some carbon and a trifle of soil-like material. The only material in the plant resembling soil is the small portion of ash. So the plant's structure is not made out of the material of the soil. It is made out of carbon obtained from somewhere, and experiment shows the carbon comes from the carbon dioxide gas in the air. In fact, in the common sense of the term, the roots of plants are really in the air. The nourishment comes from the air and is assimilated in those parts of the plants "rooted" in the air: the leaves and stem. The outgrowths, the so-called roots, are auxiliaries sent into strange regions to find water and small quantities of desirable salts. If the air were opaque and the soil transparent to human vision, we should have a juster view of the functions of plant tops and roots. We should then call what we now call the root, the top, and what is now called the top, the root. That the soil-roots of plants are a secondary development is fairly easy to see. Simple cells do not have roots. They begin to develop root-like appendages when these would be useful for collecting desirable materials, and when the cell has discovered an advantageous situation and would like to stay there. Later on, when the cell had by its behaviour implied the future human discovery of the notorious proverb: "The rolling stone gathers no moss", it grew extra-swiftly on the advantageous site. Problems of mechanics arose, for the bulky organism now subdivided into many cells required a secure system of moorage. The roots evolved various mechanical properties to fit them for their task.

The word "root" is unfortunate in the science of plants. Its very sound and associations in common

PLATE XX



[illegible] tentacles and a bud growing from the side of the body.

See page 207.

(*b*) A frog which, as Mr. Bertrand Russell puts it, "had a pin for a father." It was developed by Jacques Loeb from an egg pricked with a glass needle.
(*Loeb.*)

See page 230.

(*F. Martin Duncan.*)

PLATE XXI

4 a

living cell taken from an embryo
ick and growing in a tissue-culture
serum.

See page 209.

(*Cann & Fell.*)

A human embryo a quarter of an inch long. e slits in the neck corresponding to fish's gills present, but fingers and toes have not yet developed.

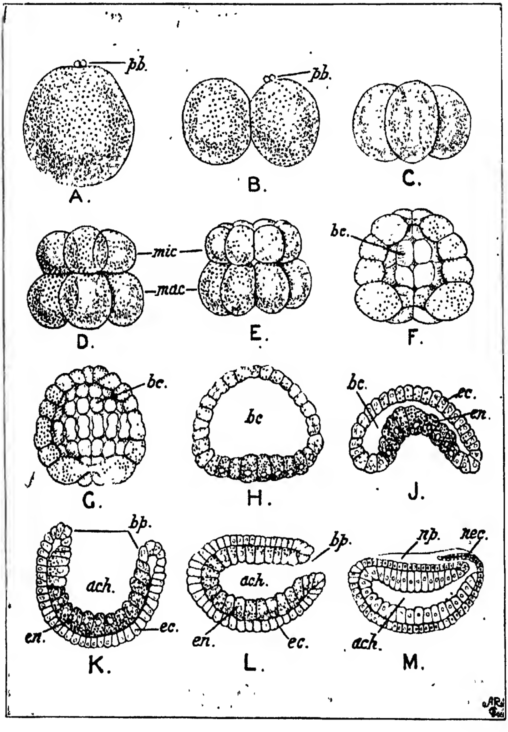
(*b*) The same embryo removed from its case, with the yolk-sac detached. The large tail is prominent.

(*Chesterman.*)

(*c*) A vertical view, showing the head.

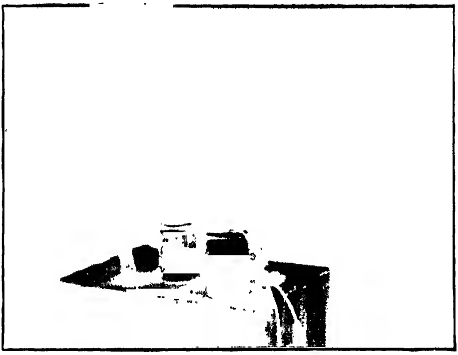
See page 216

PLATE XXIII



A to *M*. Various stages of the development of *Amphioxus lanceolatus* (mostly after Hatschek; *I*, *J*, *K*, and *L* modified after Morgan). *A*, the unsegmented ovum; *B*, the first two blastomeres resulting from the first cleavage; *C*, stage with four equal blastomeres; *D*, eight-cell stage consisting of four smaller cells (micromeres) above and four larger cells (macromeres) below; *E*, sixteen-cell stage; *F*, optical section of thirty-two cell stage showing the segmentation cavity or blastocœle, opening to the exterior above and below; *G*, a later stage, the blastocœle completely closed in; *H*, a blastula shortly before invagination; *J*, commencement of invagination of the larger granular cells of the lower pole; *K*, gastrula, with widely-open blastopore; *L*, later gastrula in which the blastopore has been narrowed by the folding together of the walls; *M*, embryo with neural plate and commencing neurenteric canal. *ach*, archenteron; *bc*, blastocœle; *bp*, blastopore; *ec*, epiblast; *en*, hypoblast; *mic*, micromeres; *mac*, macromeres; *nec*, neurenteric canal; *np*, neural plate; *pb*, polar bodies

PLATE XXIV



(*Hill.*)

(*a*) Dog standing in two pots of salt water, from which the electric currents produced by its heart are led off along the wires.

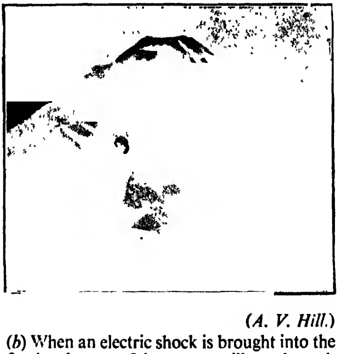
(*Hill & Melville.*)

(*b*) An X-ray snapshot ($\frac{1}{8}$th second) of the chest of a girl of fourteen, showing the lungs, heart and diaphragm.

(*Jensen.*)

(*a*) The upper picture is of an axolotl which lives in water The lower is of the same animal transformed into a land salamander by one meal of thyroid gland.

See page 296.

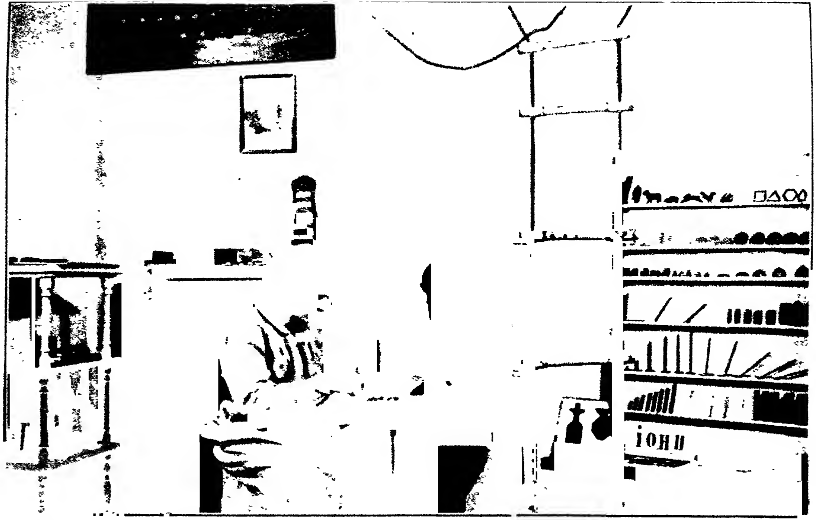


(*A. V. Hill.*)

(*b*) When an electric shock is brought into the forehead, some of the current will run through the retina at the back of the eye and stimulate the sensitive endings of the fibres of the optic nerve. These send messages to the brain, which it interprets as "light" and the subject "sees" a flash.

See page 311.

PLATE XXVI



Mme. Nadi Kohts putting her chimpanzee Ioni (his name is seen in Russian characters on the shelf in the bottom right-hand corner) through exercises in matching colours. *See page* 330.

1. Quietude

2. Sadness

3. Laughter

4. Weeping

5. Anger

6. Excitement

PLATE XXVII (Koht

usage imply fundamentality, "the root of all evil", "Aryan roots", etc., but the essential activity of a plant is in the top, not in the roots. The cells in the tops of plants are able to assimilate the carbonaceous material from the air needed for the plant's body-structure. Out of the carbon compounds assimilated from the air, water, and a seasoning of salts the plant-machine constructs its own tissue. Now if you take portions of these

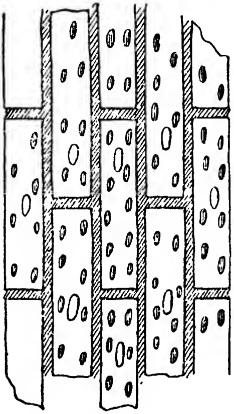


FIG. 104. Diagram of Plant Cells.

three simple substances and mix them together in a test-tube nothing, or almost nothing, happens. Certainly the substances do not burn together and release heat, as air and coal in a furnace, or food and oxygen in the digestive and nutritive system of an animal.

The plant seems to build itself up out of substances which appear as the products of combustion, for carbon dioxide and water are found in the flues of furnaces and

in the respired breath of animals. Thus the primary energy plants use in building themselves cannot come from the interaction of the substances they assimilate. Plants do not use solid, liquid or gaseous fuel for their fundamental processes, and the source of their energy is not similar to that of a locomotive, ocean liner, gas-engine or animal. What kind of fuel do they use? One similar to the fuel required to activate the receiving apparatus of a radio-set: ether waves.

Plants obtain their energy for the activities of life from those ether waves known as visible light: they are a form of solar engine. Somehow the sunlight falling on plant-tops assists the carbon dioxide from the air, and water and salts brought up with it from the roots, to combine into complicated substances which then react among themselves to produce the living material capable of self-reproduction. In this secondary activity, the plant works like a heat-engine, by oxidation of the substances synthesised by sunlight.

Examination of cells of plant-tops reveals that they have two prominent features not seen in simple animal cells. Every plant cell has a strong case of fibrous substance, so-called cellulose. The collocation of cell-cases gives plant-structures their rigidity (fig. 104). The other notable feature is the group of green oval objects in each cell, called the plastids. These little lumps lend their colour to the whole cell, and in fact are responsible for the green appearance of the plant. Most of the tissue of plants is transparent, but the millions of plastids confer on it a uniform green, as a mass of green-fly cause a brown rose-twig, as peas in a bottle of water cause it to appear green.

If the plastids are absent the plant-cell is unable to utilise the energy of sunlight for building up complex out of simple substances. They contain substances intermediarily essential in the synthesis, and responsible

for the green colour, called chlorophyll. Sunlight is able to decompose carbon dioxide, hence a cell containing chlorophyll plastids is the scene of the separation of carbon and oxygen. The carbon is combined into carbohydrates and other complex substances and these are oxidised to form the living protoplasm of the cell, while the oxygen is mainly returned to the air. Hence in sunlight when their fundamental synthetic activity is in progress, plants emit oxygen.

In the dark only their secondary reactions occur, the oxidising of the products of the synthesis into protoplasm. Here the synthesised substances are used as fuel in an engine and release the usual product of combustion, carbon dioxide. In the dark the plant works more like an animal, living on substances made by a plant, in this case itself, during sunshine hours.

The chemical composition of chlorophyll is complicated and obscure. It contains at least four substances, two of them green, one yellow, and one red. The latter is the substance responsible for the colour of carrots and is called carotin. It is also the pigment which causes salmon to be pink. Willstätter has shown that magnesium is the only metal present in chlorophyll.

Sunlight with the assistance of chlorophyll seems to be able to synthesise cane-sugar out of water and starch, dioxide. This sugar is transformed into carbon the foundation of cellulose, the material of the plant-skeleton.

Von Baeyer suggested sixty years ago that sunlight can change carbon dioxide and water into formaldehyde (the well-known preservative commonly called "formalin") and oxygen. In chemical symbols the change is:—

$$\underset{\text{[Carbon dioxide]}}{C\,O_2} + \underset{\text{(Water)}}{H_2\,O} = \underset{\text{(Formaldehyde)}}{C\,H_2\,O} + \underset{\text{(Oxygen)}}{O_2}$$

This reaction, though not yet established, would explain the origin of the oxygen emitted by plants during the daytime. Formaldehyde has the characteristic property of many carbon compounds of being able to combine with itself into new and more complicated substances. For instance, six of its molecules can combine into a molecule of glucose sugar. Hence the formaldehyde may be supposed to build up into sugar according to the formulae.

$$6\,CH_2O = C_6H_{12}O_6$$

(six molecules of formaldehyde) (one molecule of glucose)

The glucose molecules repeat the recombination trick, and build up a starch or cellulose molecule, shedding some water

$$n\,C_6H_{12}O_6 = (C_6H_{10}O_5)\,n + n\,H_2O$$

(large number of glucose molecules) (one large starch or glucose molecule) (water)

molecules by the way. This process of changing constitution by emitting water-molecules and is called condensation. The starch-like products of the synthesis are then used as ordinary fuel-food for keeping the protoplasmic cell-engines going. During the daytime the plant manufactures and stores starch and in the night the reserve is drawn upon, so the amount in leaves is less in the morning than in the evening.

All living organisms, with only one or two bacterial exceptions, depend on plants for the supply of carbohydrates, fats, and other complicated substances necessary to life. The plant transfers the energy of sunlight into chemical substances which act as energy-storage batteries, ready to break down and combine with oxygen and release energy in a form protoplasm can employ. Animals by eating plants steal these substances from them while plants devoid of chlorophyll must also steal them. Fungi flourish on other

organisms by sucking from them the juices containing the products of plant sunlight-synthesis.

Chlorophyll occupies a strategic position in the evolution of life. It works in conjunction with visible light.

In an earlier chapter it was explained that for a star of the Sun's temperature most of its energy must be emitted by waves of a certain length. If the star were hotter, the waves would be shorter and bluer, and if cooler, longer and redder. At present most of the Sun's energy is emitted in the band of waves visible as light. Organisms have evolved adapted to their environment, one of the chief factors in that is the band of waves the Sun happens to be using most for shining with at the time, and that is why plants through chlorophyll can employ visible light, and why our eyes happen to be sensitive to the predominant band of ether waves emitted by the Sun.

If the Sun had been bluer or redder, not chlorophyll but other substances would probably have been evolved to perform the chlorophylline task. The Earth is not old enough to have known the Sun in the bluer days of its youth; if it were, its fossils might have shown traces perhaps of the effects of an earlier analogue, more sensitive than present chlorophyll to blue light. The fact that such evidence as there is indicates the primal synthesis has always been made by chlorophyll suggests the evolution of life has occurred in an astronomically short time, in which the Sun has not had sufficient time to have much changed the selection of rays with which it shines.

Recently Keilin has demonstrated the existence of a substance common to all living cells, plants and animals. Cytochrome appears to have a fundamental part in the utilisation of oxygen by protoplasm, and has similarities with chlorophyll. A knowledge of the properties of a substance common to all organisms may

indicate the nature of the material from which the earliest living organisms evolved.

Since plants derive their energy from sunlight they *try* (speaking anthropomorphically) to catch as much of it as possible. They try to have a maximum area and to present it always to the light. Consequently they tend to have multiple broad and thin parts called leaves. Since on the average one place is as light as another a plant has no advantage in moving sideways. Roughly, it will find as much light in one place as another. The requirements of an animal are not for light but for the products of light: the tissues of plants and other animals. When the animal has eaten the supplies it finds in one place, it must go to another, it must move horizontally, as it is seeking solids, rather than light. The plant has to compete with others for its place in the sun and does so by growing tall or spreading its leaves over its competitors. Thus trees grow upwards to catch the light, and as the vertical is their chief direction of movement they grow upwards relatively quickly. Plants usually grow much more quickly than animals, and tend to be heavier since they require to move in one direction only and do not have to run about. For instance, the heaviest living things are the Californian Big Trees, weighing about one thousand tons, while the largest animals, whales, weigh about one hundred tons. Not requiring to move sideways plants have not evolved the delicate system of co-ordination necessary to accurate swift movement, and have no control centre for activity, no brain. Theirs is the perfect sun-bathing structure.

Some plants have avoided the labour of struggling towards the light by squatting on the tops of other plants and sending their roots into their host's tissue for the supplies of mineral salts normally sucked up from the ground. The mistletoe is an example.

Since light controls the growth and hence the structure of plants, variation in light supply should presumably affect plant-structure profoundly. Blakeslee, East and Clausen in America, Maximow in Russia and Tincker in England have obtained interesting results by submitting plants to daylight periods of abnormal length. Tincker adopted the very simple technique of running plants growing in pots in and out of a dark shed for only six, nine, or other periods of daylight hours per diem. Under these conditions, a bean plant normally growing to a height of several inches turned into a rosette of leaves. Its root fattened out like a small carrot, and proved to be edible! A new vegetable dish had been invented. Perhaps new plant products of commercial importance will be produced one day by the exploitation of this technique.

XXXV

LIVING MACHINERY

Single living cells perform all the necessary functions of living organisms; nourishing themselves, leading an active life, and reproducing. They nourish themselves for two purposes, to build up their structure and to obtain the energy for articulating that structure. They act in order to nourish themselves better, and reproduce in order to guarantee the persistence of their race.

In multicellular organisms there is a tendency to particularisation of functions. The nutrition of all the cells is assisted by special activities of a few. The waste products of the consumption of food by all the cells are extruded into general channels of exit in the body; carbon compounds from all the cells are carried to the lungs and expired as carbon dioxide through the mouth, and waste solids are discharged especially through one end of the alimentary canal. Rapid action is

guaranteed by special sets of cells called muscles, and the co-ordination of action by nerves.

A cell in the muscle of a man's leg requires food, oxygen for combination with the food in order to release energy to keep the cell going, and to supply it with energy when it is called upon to do work; and the removal of waste liquid, gaseous and solid matter. All other living cells in the body require these supplies or perform these functions when buried away in a leg or a brain or a stomach wall. In these enclosed positions they cannot directly exchange their requirements with the outside world, as a single-celled amoeba can take in food and exude waste products directly through its skin into the sea in which it lives. The problem has been solved by arranging that organisms should be able to carry their own sea with them. Every living cell in the body is bathed in a stream of fluid. From this fluid it derives food and water and oxygen; into it it exudes waste gases, liquids and dissolved solids. That the fluid is evolutionarily related to sea-water is suggested by its composition. The chemicals dissolved in it are similar in selection and roughly in proportion to those found in sea-water. Evidently the separate cells of which complicated organisms are composed have not been able to evolve themselves very far beyond the stage their ancestors achieved in the sea. They have not found another and better way of living than being surrounded by a sea-like fluid. Individual cells seem to have come to something of a stop in the evolution of cell-mechanism. For instance, they have not evolved into balls of self-reproducing flame, or self-acting electric dynamos made of metal, or stable living interactions of gases at low temperature and pressure. Not having evolved mechanisms of these kinds, cells and hence large conglomerations of cells such as men, cannot live in flames, or pioneer stellar space. Cells have not evolved

with the appropriate properties, and have been narrowly restricted to a type of food, water and oxygen mechanism so specialised that organisms made of them often do not easily accommodate themselves to so relatively similar environments as Arctic and Tropic climates. Eddington has estimated the average temperature of matter in the Universe to be 15,000° C. The range of active life is between 273° and 373° absolute, i.e., between 0° and 100° C., the freezing and boiling points of water.

Cells have become organised into the higher organisms not only by change and improvement of cell-mechanism, but also by co-operation and specialisation. Life seems to have decided to entrust future evolution to the development of organisation rather than radical self-improvement or development enabling it to live in stars at 10,000,000° C. or in cosmic space at —272° C.

This conservative tendency is shown in the higher organisms taking a sea-like environment along with them, for all cells are streamed by the blood, and the animal's skin keeps the blood from flowing away. The blood carries food and oxygen to the cell, and bears away waste products in the form of carbon compounds and urea.

XXXVI

BLOOD AS AN OXYGEN DISTRIBUTOR

SINGLE cells living in water derive their necessary oxygen from that dissolved in the water. The dissolved oxygen passes through their skin. In the lower organisms such as jelly-fishes, oxygen is obtained also through the skin. Even a resting frog can live if it is able to get oxygen only through its skin. An inactive organism not requiring a rapid production of energy does not require a prolific supply of oxygen. The small quantity dissolved in water is sufficient if the organism has the time to wait

for the water to dissolve fresh oxygen from the air as fast as the dissolved oxygen is removed. The slight solubility of oxygen in water places a crippling brake on the utilisation of water-borne oxygen for respiration, since two hundred volumes of water will dissolve only two volumes of oxygen. Evidently an active inner body-cell would require a very copious stream of water if it had to depend only on water-dissolved oxygen. This great bulk of water would in turn impede the organism and make it clumsy. For active cells the serving fluid should be a vastly better solvent or absorbent of oxygen than pure water, and accordingly, in the higher organisms it is. Blood absorbs forty times as much oxygen as an equal volume of water.

Consequently, the human heart is forty times smaller, or beats forty times less quickly than it would have to do if blood absorbed oxygen no better than water.

The increase of oxygen-absorbing power in blood is due to an interesting example of cell specialisation. A certain race of cells evolved the art of manufacturing a peculiar iron compound capable of combining with oxygen very easily. The cells developed a disc-like shape so that the largest possible area of this compound was exposable to oxygen, and were multiplied in very large numbers. Their earlier cell-structure has degenerated and now in mammals contains no nucleus, so the mammalian red-blood corpuscle is not wholly alive. The red colour is due to the oxygen-absorbing substance haemoglobin. A normal man probably contains 20,000,000,000,000 red-blood corpuscles and their area is probably about 1,500 times the surface of his body. Thus the blood contains about one-third of an acre of haemoglobin surface for dealing with oxygen. The inner cells are provided with oxygen by the blood carrying to their supplies of oxygen-loaded corpuscles. After releasing the oxygen for the cells the corpuscles have

to move on, deprived of their oxygen load, to make way for the corpuscles approaching from behind. The blood has to be kept in circulation. An organism possessing an oxygen-carrying blood-stream requires a pumping mechanism, and this is provided by the heart.

Fundamentally the heart is a muscular elastic enlargement in the blood pipe-system, which subjects the passing stream to systematic squeezing to make it go

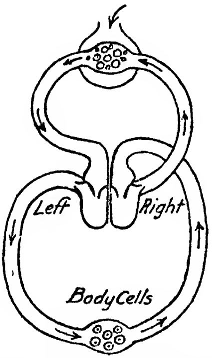


FIG. 105. Schematic Diagram of Blood Circulatory System

through all the pipes. The arrangement is shown schematically in fig. 105. The blood arrives at the body-cells charged with oxygen and free from waste carbon products. The cells abstract the oxygen-charge and discharge the cell-waste into the stream of stale blood, which flows on to the heart, to be pumped through the pipes of the blood-line exposed in the lungs. These tiny pipes, called capillaries, are so small and their walls so thin that carbon compounds can easily pass through

them from their contained liquid, and oxygen easily pass from the air in the lungs through the pipe-walls on to the haemoglobin layers of the blood-corpuscles. The transferences of oxygen, and wastes at the cells, are also done through the walls of small capillary pipes. The blood pipe-system has two regions of multiple construction, where the pipes are going through lungs, and by cells. They split up into a vast number of fine-bored branches. Fluids flow through fine-bore tubes less quickly than through large tubes due to the increased effects of viscosity or stickiness of the fluid, and friction. The heart has to drive the blood-stream with considerable power to cause it to pass through the various capillary restrictions at a reasonable pace. If there were no capillaries nothing more than a gentle urging would be necessary. The heart actually pumps the blood out of itself at a pressure of about five and a half feet of water, which means that the blood from a punctured artery would spurt five and a half feet up into the air. In the large arteries near the heart the blood flows at a speed approaching two feet per second, while in the capillaries, the speed drops to about one-fifth of an inch per second. When people stand very still for some time they tend to faint, as soldiers on parade without proper "stand easy" pauses. This is due to the accumulation of blood in the veins of the legs and the consequent deprivation of the brain's supply of blood. As soon as the man moves, his veins are stretched again and the blood-circulation rate improves.

The obstruction of the capillaries in the lungs and body-tissue causes the blood which has passed through them to ooze onwards slowly. Consequently, the pipes conducting blood away from the scenes of chemical change contain slow-moving blood and are called veins; the pipes bearing the blood under pressure from the heart to the scenes of chemical change are called arteries.

Plain haemoglobin is purple in colour, and red when combined with oxygen. Consequently the blood in veins is purple and that in arteries red. The oxygen drawn from the haemoglobin for use in the cells is used partly for burning carbon compounds in order to provide energy for the cell and substances for its structure. The carbon dioxide formed in the process is partly dissolved as a gas in the blood, but mainly carried in solution as a compound with sodium, sodium bicarbonate. In the lungs the dissolved sodium bicarbonate is decomposed and carbon dioxide released, and so the carbon dioxide of the expired breath is produced.

XXXVII

BLOOD AS A FOOD DISTRIBUTOR

Western peoples take three or four meals a day. The time consumed in sitting at table and masticating amounts to about one-eighth of human life and one-fifth of the species' waking hours. Yet chewing is the simplest and trivialest part of digestion. The really intricate and serious part of the mechanism of digestion is performed subconsciously by healthy organisms.

The progress of civilisation does not seem to have revealed these facts clearly, since material prosperity has probably caused over-eating to be commoner to-day than in the past. The abundance of food gives gluttony the opportunity, and bored prosperous people often relapse into eating for the sake of something to do. In any large restaurant those are always to be seen who make eating a substitute for conversation. Yet conversation is probably the most important part of meals. The social exercise of the mind under conditions preventing serious mental concentration and responsibility is one of the most delightful and valuable

of human activities. Eating becomes less and less the real business of meals as the preparation of food becomes more complex and scientific. In the future the minor activities of chewing and masticating will be done in the kitchen for those without conversation and who wish to rush straight from the office to the card-table.

Food masticated in the human mouth is broken into pieces and mixed up with saliva. This makes it easy to swallow. A mouthful of slippery well-masticated food reaches the stomach in a few seconds, while a rough tablet may take a quarter of an hour. Three pairs of glands exude the saliva through ducts into the mouth, one pair being those subject to the inflammation called mumps. The saliva also commences the disintegration of the food into substances the cells of the body can reabsorb. This chemical dismantling is achieved through auxiliary substances called enzymes. Their function is similar to that of a catalyst, something which enables two substances to react together without being permanently changed itself, as if it were a link or pipe which enabled fuel to pass from the bunkers to the furnace. The molecules of the catalyst pass, as it were, into the bunker and seize molecules of fuel and bring them into the furnace where they can react with oxygen and release energy. But the fuel-molecules could not without the exchanging help of the enzyme molecule have passed from the bunker to the furnace. Saliva's particular enzyme is called ptyalin and disintegrates starchy material into a sugar of simple molecular structure. The chemical disintegration of food has commenced already in the mouth, but has not proceeded far. If man could synthesise ptyalin, suitable quantities of it could be mixed with thoroughly crushed food so that the necessity for mastication would have been eliminated. After swallowing, the mouthful arrives in the stomach and is thoroughly squeezed, and attacked

by several more enzymes and free hydrochloric acid. The starchy parts of the mouthful are disintegrated further into simple sugars, while the enzyme pepsin in the presence of an acid causes the fleshy parts, the proteins, to disintegrate into simpler molecules of the same type. The fatty parts of the mouthful are not affected much by chewing and stomaching.

After from one to four hours of squeezing and enzyme-attack a meal is discharged in squirts into the beginning of the intestine, whose first part has a surface covered with little piles, like a very fine india-rubber mat. The unevenness enormously increases the surface area, for if the small intestine were smooth its area would be only about five square feet, but with the unevenness it is increased to about 50 square feet. The products of the stomaching by acid and enzyme are spread over and over this 50 square feet of absorbent surface, which absorbs many of the simpler products of the disintegration of the food as if it were a piece of super-blotting paper. The already battered food from the stomach is engaged, as it were, on a very much extended front. No sooner is it in the smaller intestine than it experiences a very powerful attack from the rear. Just by the hole through which it passed from the stomach are two smaller holes, the ducts from the liver and the pancreas. These glands pour more disintegrating substances on to the half-disintegrated material. The liver produces bile which causes the still-unchanged fat to be dispersed into a milky cloud of fine particles. This operation enormously increases the area of the fat, for a given weight of substance has an immensely greater area when finely subdivided. The area of the fat having been greatly increased, it is the more easily attacked by the enxyme from the pancreas which has the ability of taking complicated molecules of fat to pieces. In many of these reactions the prominence of surface-increases is noticeable. Evidently living

processes much employ the properties of surfaces in achieving the vital mechanism, and this hint suggests that in the cell, where comparatively so little is to be seen, much happens at invisible surfaces. A deeper knowledge of cell-mechanism would seem to depend on the invention of a technique capable of determining the position and activities of these speculated surfaces. When the bile-duct is blocked, as in jaundice, the patient cannot digest pieces of fat such as suet because there is no bile available to disperse it. He can digest the fat in milk because that is already dispersed in fine droplets. The bile contains pigments made out of the haemoglobin from worn-out red-blood corpuscles. This colouring matter causes faeces to have the yellow colour. In jaundice the bile-duct is closed and the patient's faeces are white. The bile-pigments escape into the tissues, which consequently become yellow.

As a consequence of the actions of the acid and juices in the stomach, and the alkaline juices in the small intestine, the large molecules of material in food are disintegrated into smaller molecules. These consequently can pass more easily through membranes, and most of them penetrate the surface of the intestine and collect in the veins running from the intestine to the liver. The fat molecules are disintegrated into glycerine and fatty acids and the latter combine with sodium to form soap-like substances, and are delivered ultimately into the jugular vein in the neck.

A heavy meal of fat may cause the blood to have a milky appearance. After the disintegrated food passes through the surface of the small intestine it has to go to the liver, for the veins proceed there. In the liver the various disintegration products are sorted out, sugars being stored mainly on the spot, or converted into fat for storing elsewhere. Ammonia from the disintegration of proteins is converted into urea by combination with

carbon dioxide. If a person has an excessively large meal of meat his liver may be unable to cope with the excess of ammonia produced in digestion, and this may pass into the blood and reach the brain, causing convulsions.

The small intestine pretty well absorbs out all the useful products of digestive disintegration and passes most of them on to the liver. Those it can do nothing with are pushed into the large intestine. The surface of the large intestine absorbs mainly water from the débris and is convenient rather than necessary. Persons whose large intestines have been removed often lead healthy and active lives. The organ is something of a relic from the stages of evolution when man's ancestors lived on coarser food and had to digest uninviting food such as woody fibres and dried skins such as leather, which mice can live on to-day when they are pushed to it.

Organisms are rather like those architects who buy old buildings, disintegrate them into beams, bricks, and tiles, and integrate the materials into a new building sometimes more, sometimes less elegant than the original. The process seems inefficient. Plants and animals have to build up very complicated substances and humans take these substances and disintegrate them before incorporating the parts into their own bodies. Why could not man receive the comparatively simple sugars, fats and amino-acids directly into his blood-stream and cut out digestion altogether? If these could be synthesised doses of them could be injected directly into the blood. As they are the simpler substances of their kind, synthesis of them in the laboratory is not beyond hope.

The blood derives its supplies of sugar, fat and amino-acids from the intestine mainly through the liver, and distributes them to the cells of the body for utilisation

as fuel to supply the energy required for action and for the increase and repair of the stuff of the body.

XXXVIII

THE BLOOD-STREAM AS SEWER

THE blood carries dissolved food from the liver to the various cells of the body and bears away from the cells the waste products of their activity. The carbon dioxide made in the cell by the oxidation of carbon compounds is carried in the blood mostly in the form of sodium carbonate to the lungs, where it effervesces from the blood through the thin walls of the capillaries and thence is respired in the breath. Some moisture is carried away also, since the breath is damp. The solid and liquid waste products such as urea, uric acid and some sulphuric and phosphoric acids, are carried away from the cells in the veins. They have to be removed before the blood is re-charged with food-substances by the liver and re-oxygenated in the lungs, and again pumped by the heart to supply the cells with oxygen and food.

The purifying is done chiefly by the kidney organs. The liver also performs a purifying function when it deals with the disintegrated food molecules delivered to it from the small intestine, for not all of the molecules are suitable for food and some require to be changed before the kidney can remove them from the blood. The ammonia is changed to urea by the liver, and delivered back into the blood-stream. The kidney, which cannot deal with ammonia, has no difficulty in separating out the urea. Other dangerous substances transformed by the liver are indol and skatol. These are produced in the intestine by bacteria. The liver seizes and transfixes them into a compound the kidney can deal with easily. It has been mentioned that the liver collects the break-

down products of red-blood corpuscles and emits them in the bile and hence into the bowels. Various organs not primarily concerned in purifying the blood and acting as sewage disposal plants assist as minor sanitary officers. The salivary glands, for instance, excrete molecules of potassium sulphocynate the liver has manufactured out of prussic acid treacherously delivered into the blood as a cell waste product. Sweat glands are chiefly concerned in the regulation of the temperature of the body, but they also excrete urea and excess water and a little salt from the blood. The large intestine passes difficultly soluble substances such as phosphate of lime from the blood-stream through its walls, saving the kidneys from

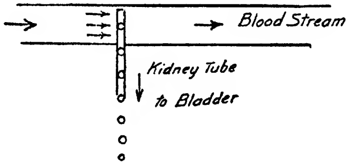


FIG. 106.

the risk of being choked by crystals of this easily deposited material.

The kidneys are the main purifiers and regulators of the composition of the blood. Essentially they are bundles of fine tubes inserted in the blood-stream. In man each kidney contains about a million of these little tubes. The number implies that their surface area is great, so that large quantities of blood can be strained through the tube-walls in a short time. Once more the importance of surfaces in living organisms is manifest. The walls of the tubes are adapted to keep the composition of the fluid on one side of them constantly to a fixed recipe; if the composition changes then constituents are taken out altogether, or altered in proportion until

the correct composition is restored. The molecules coming through the walls of the kidney tubes are drained away to the bladder. As they are not of the largest size, they do not contain red-blood corpuscles or the large molecules operant in the clotting of blood. Being free of red corpuscles the urine collecting in the bladder is not red. The rejected liquid in a healthy person is mainly water; about 96 per cent, by weight. About 2 per cent. is urea, and about 1 per cent. is common salt and 1 per cent. other substance including uric acid. The kidneys can deal with substances in dilute solution only, consequently they excrete a large amount of water. When the uric acid is not entirely removed in the urine it tends to accumulate in the subject's joints. The crystals give his tissues sharp pricks, the excruciating pains of gout. Deposited uric acid is not easily removed, though some preparations are said to dissolve them. Electrical treatment often helps. The patient places his feet in water and a currect of electricity is sent through his legs into the water. The uric acid ionised molecules pass slowly through the skin into the water if the current is sent in the right direction, and the water becomes acid from the crystals dissolved and moved from the gouty joints.

Failure to dispose of material removed from the blood sometimes causes deposits of solids to accumulate in the kidney, producing the unpleasant stones which later come loose and reach the bladder, giving the patient much pain while being voided. They are composed mainly of calcium oxalate.

In hot weather, when sweat removes much water from the blood, the percentage of salt in the urine increases.

In extreme exercise, such as hewing coal in a deep hot mine, sweating is so copious that appreciable quantities of salt as well as water are exuded through the skin.

The salt content of the urine then decreases. The miner develops a tremendous thirst and sometimes drinks so much water that his blood is seriously diluted in salt content, even though the kidneys are not removing salt. The kidneys then rapidly remove a large quantity of water from the blood, and the urine is almost pure water. Even this rapid reduction of water content and hence increase in salt concentration in the blood is not sufficient to restore the normal blood composition. Then the miner sometimes gets abdominal cramp, which can be cured by drinking slightly salty water. Apparently miners and other heavy sweaters have found this out for themselves, since Cornish tin-miners eat much salted fish, Yorkshire miners consume famous Yorkshire salted hams, other miners take salt in their beer, and the importance of salt to Oriental coolies is well known. Extreme sweating evidently overtaxes the ability of the kidneys.

The concentration of the other substances in the blood is regulated in a similar way. If there is too much sugar in the blood the sugar content of the urine increases. In diabetes the patient's pancreas has partially broken down and fails to regulate the sugar-production, so an excess of sugar appears in the urine.

If insulin is injected into the patient's blood-stream, it reduces the sugar content, and the excess is eliminated. Alternatively, the patient may be fed on foods containing no sugar nor materials from which the liver can synthesise excess of sugar.

The kidneys have very actively to control the rate of solutions passing through their tube-walls, sometimes holding back molecules and sometimes thrusting them through to restore the blood constitution rapidly. Weight for weight the kidneys work harder than the heart, and consume a greater proportion of energy and so have a greater rate of oxygen consumption.

When hard pressed they can increase their fraction of a horse-power, like the heart, by three or four times.

XXXIX

ATHLETIC CELLS

The collections of cells specialising in movement are called muscles. Each cell of a muscle has the property of being able to change its shape rapidly, and when all of the cells are stimulated to change their shape at once the muscle they constitute changes its shape and tugs anything to which it is attached. In (*a*) there is a schematic diagram of the bones, muscle and tendons of an outstretched arm. In (*b*) a representation of the arm bent. The muscle has contracted. The four quarters of the muscle have changed in shape from rectangular blocks to cubes. When the muscle is divided into its

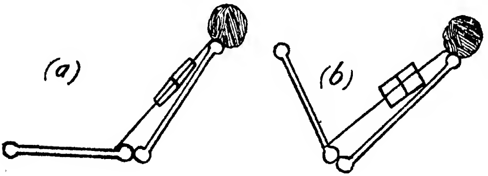


Fig. 107.

individual cells, a corresponding difference of shape in the cells before and after contraction is noticed.

About half of the total weight of the human body is contributed by the muscles, and they contain millions of cells. One of the reasons why nature has not been able to evolve large single cell organisms but only large conglomerations of small cells is suggested particularly by a consideration of muscle-cells. These

have to change their shape quickly. Rapid movements cause great strains in large objects, so there is a limit to the speed with which large objects can be moved. Professor A. V. Hill has illustrated the point by considering what happens if a long glass rod is shaken in the hand. It snaps off. A rod of quarter the length and thickness may be shaken very much faster before it snaps. In practice, a compromise must be made between speed of movement and liability to break into bits, and nature has observed the compromise very well. An eyelid may be winked much faster than a punch may be delivered because it is smaller than a fist and does not develop such large internal strains if accelerated at any speed. The wings of some insects beat about three hundred times a second, while a galloping elephant may take more than one second to move a leg. If an elephant's leg were moved backwards and forwards as rapidly as a hornet's wing it would be shattered. The beginning of this effect may be seen in the results of excessive exercise in men. They feel stiff and sore afterwards, which is probably due to tearing of the muscle cells; and may possibly tear whole groups of cells; in which case they have "torn a muscle" or ruptured themselves. Sometimes the strain on the tendon joining the muscle to the bone is so great that a piece of the bone comes away with it. Then the muscle and tendon have shown a greater gross tensile strength than the bone.

It is not always necessary for muscles to act quickly. Those in the outside of the body, which move or assist to move it about in space and in competition with other animals are specially developed for speed. Movements of legs and hands specially require to be quick. Muscles inside the body are not so directly subject to competition. For instance, the muscles of the stomach do not have to compete in the race for food with the muscles of other people's stomachs. Once they contain food they have

it at their mercy and can take their time over dealing with it. Their speed of movement need be no greater than is necessary to supply food as quickly as the cells of the body can assimilate it. If the stomach muscles and the digestive processes worked so quickly that a large meal could be digested in one minute, the body-cells would suddenly have food flung at them and be choked. Muscles therefore can be divided into two classes, those which may have to work at maximum speed and those which work at leisure. Nature has developed their constituent cells differently. The first sort, such as the muscles in a leg, are of fibrous appearance and made of millions of long thin cells capable of changing their length very quickly, while the other sort such as the muscles which operate the intestines is made of shorter cells whose shape is not adapted to rapid change and presents a smooth appearance.

The fact that muscle-cells can change their shape and hence emit considerable quantities of energy in a short time has allowed interesting knowledge of cell economy to be obtained by clever experimenters. Since the muscle changes or tries to change very quickly, the ordinary processes of feeding and building and repair of the cell are negligible during the short period of strain. Suppose a small muscle is tied in a little box containing an exceedingly sensitive thermometer. Since the ends of the muscle are tied, it cannot change its length, but it can strain itself and emit energy trying to, if the muscle is given a stimulus: an order to work. Since the muscle cannot move, it can only get hot with straining. The amount of heat is measurable by the thermometer. For one twitch, the rise in temperature is about $\frac{3}{1,000}$° C. Now the changes in chemical constitution after the strain can also be measured, and it is found that the heat produced is equal to the amount of heat released by the various chemical changes in the muscle cells. This proof of the

observance by small intimate groups of cells of the laws of physics and chemistry is striking, and reduces the tendency to assume that living organisms obey laws which disagree with those of physical science. When the box contains oxygen the muscle will continue to produce energy after repeated stimulations, but if nitrogen is substituted it soon becomes fatigued. Evidently muscular movement is closely connected with oxygen consumption. The muscle-cells contain considerable quantities of a substance called glycogen. This material is directly engaged in supplying the energy the cell uses in changing its shape, it corresponds to the petrol in the tank of a motor-car or the lead oxide in the plates of a charged accumulator. When the cell-engine is caused to work the glycogen disintegrates into lactic acid and releases energy. This change corresponds to the reduction of the lead oxide to pure lead. During a hundred yards' race in which an athlete spends all his available energy about one ounce of lactic acid appears in his muscles. He will not be completely recovered from the race until his muscles are free from lactic acid. Energy is needed to convert the lactic acid back into glycogen, and is provided by the combination of some of the remaining glycogen with oxygen. Thus glycogen takes part in two reactions during the movement of muscle-cells. Some of it first of all provides the energy for the muscular movement. Then some more of it combines with oxygen to reconvert the lactic acid into glycogen: the substance is both being made and consumed during the recovery of the muscle, but is consumed only and not made during muscular action. The consumption of oxygen is during the period of recovery. This is illustrated by the fact that a sprinter can almost equal record time over a hundred yards even if he holds his breath throughout the race. He begins to breathe heavily after the race, and the extra oxygen he inspires will

penetrate through his blood to the muscle-cells and combine with glycogen there to provide energy to remove the lactic acid. The phenomenon is seen more particularly in the little box containing the small muscle fibre. The fibre continues to emit heat for a considerable time after the attempted contraction; in fact, 50 per cent. more heat is emitted after than during the twitch. The sudden output is due to breakdown of glycogen, the slow cumulative output is due to the oxidising of lactic acid back into glycogen.

Fatigue after muscular exercise is due to the muscles being soaked with lactic acid. This appears to interfere with the delivery of the stimulus which makes the muscle move. Possibly it interferes with the electrical conductivity of the surfaces of the muscle cells. Prof. Hill has remarked that after a race one's legs do not feel tired, but rather seem to refuse to move. The lactic acid somehow prevents the muscles from receiving the message from the athlete's brain ordering them to work furiously. The effect is perhaps somewhat similar in nature to that of the drug curare used by Indians for poisoning arrows. When the arrow pricks the victim the curare on the barb penetrates into the blood and on to the surface of the muscle-cells. In particular it blocks the places where the muscles join the nerves bringing the order of action from the brain. It is odd that lactic acid, the substance giving the characteristic taste to sour milk, should in another situation cause the symptoms of muscular fatigue by a kind of paralysing action somewhat similar, though milder, to that of the peculiar drug curare.

The behaviour of cells in an atmosphere of nitrogen has stimulated some speculations on the nature of vital machinery. After the cells have been deprived of oxygen for a considerable time they begin to emit heat due to the disintegration. If oxygen is admitted the temperature

is reduced to normal again, providing the disintegration has not gone too far. Thus oxygen may under certain circumstances reduce the rate at which cells produce energy, and act as a governor on a complex of chemical interactions. Oxygen may be imagined as one of the parts, one of the chemical wheels, as well as the burner of fuel, in cells. When the cell is deprived of oxygen it gradually begins to emit substances resembling those from a malignant cancer cell. May malignancy in body-cells be due to defect in oxygen-control? This suggestion arising from the researches of Warburg and Hill shows the cancer problem in a new perspective. It arose from work unconnected with direct cancer research, and is one more illustration of how fundamental research is always illuminating unexpected places, and of how the solutions of scientific problems tend to be found away from the apparently obvious region of research, since one would expect the nature of cancer to be learnt from a study of cancerous rather than normal cells. Recently, however, the phenomena discussed in this paragraph have been shown to be due to osmosis, not oxygen.

Why cells should be able to change their shape rapidly and thus constitute muscles is not yet known. It is perhaps due to a change in the structure of substances in the cell similar to that in india-rubber, which becomes semi-crystalline when stretched. The change in structure entails a change in shape. Perhaps it is due to a change in the condition of the surface which enables fluid to soak through swiftly and expand the cell, as water puffs up a dried bean; or perhaps the change is due to rapid colloidal swelling, as if the muscle-cell were a piece of jelly expanding rapidly after being suddenly exposed to water.

XL

ELECTRICITY AND CELLS

The human body and the more complicated organisms have their sets of athletic cells which enable movements of all kinds to be made. If the numerous muscles of the body were unco-ordinated they would not be of much use, since actions would be chaotic.

A muscular system is useless without a system of control; and consequently nature has evolved the nervous system. Like all other tissues, nerves are made of cells. As muscle-cells have specialised in mobility of shape, nerve-cells have specialised in structure and conductivity. Organs reacting as quickly as muscles need a very swift controlling system to co-ordinate them.

Prof. Hill has pointed out that in an organism consisting of a single cell rapid systems of communication between different parts of the cell are not very necessary. If a particle of one part of the cell is needed in another, it can just go and get there, quickly. In a large and complicated organism such as a man or elephant, this is not always possible. A particle required in the head could not very swiftly travel there from the toe. For moderate speeds it would be possible, and indeed happens when excessive carbon dioxide is discharged into the blood during muscular exercise and carried to the brain, where it causes the order to be given to the lungs to breathe more quickly. Such a mode of communication would not do for advising the brain that a tiger or a motor-car was about to hit its owner. To be of any use in such circumstances an almost instantaneous advice is necessary, in fact, organic telegrams if not radio messages must be sent in many directions if the danger is to be avoided. Consequently, the higher organisms require

some system capable of conveying information without moving particles over great distances; a biological telegraph in contrast to a biological post in which material objects such as molecules or carbon dioxide travel as the letters. Nature has proved not unequal to the demand. All the higher organisms have their telegraph system, and an electric system, too, though the electricity is not used in the same way as in the familiar telegraph or radio.

The nerves are the lines of the system. When examined they are found to consist of bundles of exceedingly fine fibres. One would expect the fibres to be portioned off occasionally into cells, but investigation reveals no cell nuclei, the characteristic of cells, in them. From the end of the nerve in the muscle through all its length in the body, no nuclei are discovered in the conductive part of its fibres. This is remarkable, since it seems to suggest that after all living tissue can exist in comparatively large units and yet not be organised into a cell.

Apparently nerve-tissue is an exception to one of the great generalisations of biology. A careful search does, however, reveal nuclei in nerve fibres. When traced, most nerve fibres are found to proceed to the spinal cord or brain. Inside the cord the nerve-thread-ends are found to contain nuclei. So the fibre is nothing more than a hair on the body of a cell living in the spinal cord, a gigantic whisker, as if a telegraph wire were a whisker sprouting from the transmitter. These whiskers may be several yards long, as in an elephant or a man where a nerve-cell is situated in the brain (which is an elaborate knot on the top of the spinal cord) while the vast hair sprouts down tunnels in the body to, say, a big toe.

This sprouting character of nerves accounts for the possibility of some remarkable cures of injuries due to damaged nerves. If a nerve is cut, the part disconnected with the nucleus dies.

Later the remaining part containing the nucleus may grow again and the sprouting fibre creep along the channel where the old extension had been. Finally, in some cases the nerve-fibre reaches the muscle or organ it previously ended in, and the patient suddenly finds the use of the organ restored to him. This extraor-

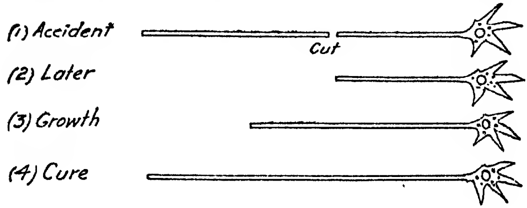


FIG. 108.

dinary property of human telegraph wires being able to mend themselves after a storm has been exploited brilliantly by surgeons. Sometimes a person's face may be paralysed by failure in the functioning of the nerves connecting them with the cord and brain. It is possible to cut these nerves and arrange for good nerves operating comparatively unimportant muscles in the shoulder to

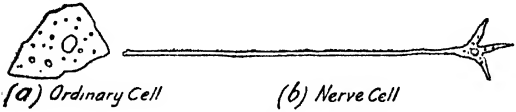


FIG. 109.

grow along the channels left by the faulty nerves, finally joining on to the facial muscles. The messages from the brain reach the facial muscles safely through these good diverted nerves, and the subject now finds he can control his expression. Many other changes of the same kind are possible.

The weight of a nerve-cell may be not much more than that of other cells, because the fibre is very thin, but the length may be enormously greater. If a nerve consisting of a bundle of these fibres is removed from an organism the passage of electrical disturbances along them can be directly detected with electrical instruments. In fact Galvani began in 1761 his famous researches resulting in the discovery of electric currents from an observation that if frog's legs were suspended on an iron railing by copper hooks, they twitched occasionally. The iron and copper and moisture on the railing were really forming a little electric battery whose current caused the twitching.

By measuring the time that the electrical disturbance takes to pass down a known length of nerve the speed of propagation can be calculated. It comes out at about 400 feet a second for a human nerve. This is quite fast, but so much slower than the rate at which electrical waves travel (186,000 miles a second) that it indicates the nerve-message must be only partly electrical. Very delicate instruments show that one message passing down the nerve raises its temperature about one millionth of a degree Centigrade. This is an indication that the message is also partly a chemical phenomenon producing heat. The nerve-message appears to be an electro-chemical activity.

Nerves are collections of single cells whose nuclei are concentrated mainly in one region: inside the spinal cord, and whose fibrous extensions penetrate to all parts of the body. Down these fibres electro-chemical messages flow, but always inside the single cells, and their fibres. The nerves are not chains of cells with currents passing from one to the next. Why should the nuclei of the cells be in one region? For the same reason that all telephone wires go to an exchange. It is much simpler to send all calls to an exchange from which they can be directed. Without an exchange all

subscribers would have to be connected with each other. Instead of having one wire, Jones would require just as many wires as people whom he wished to call. So with nerves, if organisms did not have a centre of exchange for nerve-messages, every part of the body would have to be connected with every other part, and an organism would look more like a ball of woolly nerves than an economical articulate mechanism.

Perhaps the nerve-messages are restricted to the insides of single cells for purposes of insulation. If the messages could jump across from one cell to another they might be able to leak all over the body and cause a chaos of reactions. Nerve-cells are not the only ones showing electro-chemical currents. Muscle-cells, the heart-cells and those of the glands and eyes also produce electric currents. The currents from the heart tell much of how it is working, and the modern achievement of having them register their quantities on a photographic film is a great contribution to medicine.

The subject places organs some distance apart into jars of salty water. As the heart beats its currents pass through the body to the jars and thence by wires to the instrument registering their magnitude and variation (Plate XXIVa). An X-ray photograph of a girl's heart beating is shown in Plate XXIVb.

Some of the characteristic electrical properties of nerves may be expected from what is known of the electrical behaviour of solutions of salts.

Suppose a porous pot of unglazed clay is placed in a bowl of water, and its inside is filled up to the water-level outside with a solution of common salt. In solution, much of the salt dissociates into atoms of sodium and chlorine wandering about by themselves. The chlorine atoms are represented by O's and the sodium atoms by □'s. If wires are placed in the water on opposite sides of the porous pot, and connected to

the terminals of an electric battery, one wire will be positively charged and the other negatively. In fig. 110 the positively charged sodium atoms will tend to flow from right to left, and the negatively charged atoms from left to right. Thus there will be a banking of chlorine

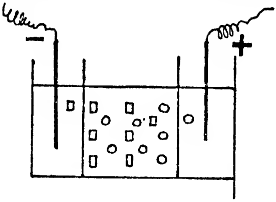


Fig. 110.

atoms against the right side of the pot and of sodium atoms against the left. Something of the kind happens in living cells when wires from a battery are placed on opposite sides of it. The skin of the cell acts as a semi-porous membrane, and charged atoms of various kinds in the cell-fluid bank up on opposite sides as near as

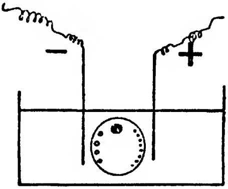


Fig. 111.

possible to the wires (fig. 111). If the electrical pressure from the battery is high enough, some of the charged atoms may break through the cell-skin and cause a sudden disturbance. The cell is slightly convulsed, and twitches; it is said to have been stimulated.

The effect of a slight shock on a nerve-cell may be considered with this idea in mind.

Fig. 112 represents a nerve-cell at rest. Owing to the nature of the cell-skin there is a separation of negatively and positively charged atoms. The number of atoms of each kind may be the same, so that the cell as a whole bears no charge, but contains electrical strains owing to the separation of the two kinds of charged atoms. Suppose the nerve-fibre is cut at A. The fibre will be open at the end and fluid will ooze on to the outside of the fibre, and make a conducting connection with it. Thus the negatively charged atoms outside will tend to flow inside and cause an electric

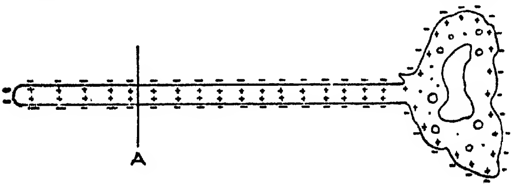


FIG. 112.

current to flow up the inside of the fibre. A galvanometer with terminals attached to different points in the nerve-fibre will register this passage of current. This sort of electrical disturbance in nerve-fibre is called the "injury current" and is caused when the fibre is struck or damaged sufficiently for the re-arrangement of the charged atoms on the inside and outside of the fibre to occur. When the nerve-fibre is given an electric shock, the sudden change of electric pressure at the point of application is equivalent to physical injury in so far as a current is sent down the fibre, though the fibre is not damaged permanently, only momentarily upset.

This suggestion of the nature of the occurrence in a fibre when it is stimulated perhaps furnishes one reason

why nerve-fibres are made of single and not chains of cells. If the fibre were apportioned into cells, there could not be a uniform electrical condition throughout the inside and outside of it. Consequently when stimulation or disturbance occurred a general readjustment would occur only in that particular cell in the nerve upon which the stimulus happened to fall. There would not necessarily be a readjustment throughout the whole length and breadth of the nerve, as would be probable if the fibre were all part of one cell.

This explanation of how cells are stimulated explains the remarkable fact that alternating electric currents at very high voltage do not necessarily injure an organism. When the current is switched on to the organism it

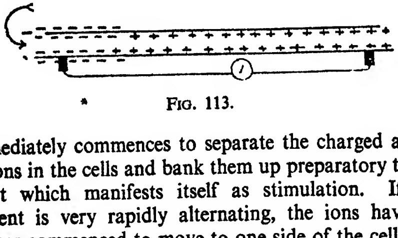


FIG. 113.

immediately commences to separate the charged atoms or ions in the cells and bank them up preparatory to the burst which manifests itself as stimulation. If the current is very rapidly alternating, the ions have no sooner commenced to move to one side of the cell than they are urged in the opposite direction, due to the change in direction of the current. Thus even if the voltage is very high, a million volts for example, so that the ions are impelled exceedingly swiftly to their respective sides of each cell, none of them will get there if the current alternation is sufficiently rapid. This explains how people can draw large sparks off their nose and body without feeling anything. If such sparks had been due to a direct current they would have been killed instantly. Persons accidentally touching the electric light mains often receive a nasty, sometimes a fatal

shock. The frequency of the current in these mains is usually about fifty a second, quite a small number. If the frequency were transformed to five hundred thousand a second they would feel nothing whatever.

The message travelling along a nerve is a wave of readjustment. When it is passing any place it is readjusting the electrical relations between the charged atoms of substances on the spot.

The muscles of the body operate locally. For instance, the forearm is lifted by muscles in the upper arm, and the leg by muscles in the leg. They are all connected by nerves to the spinal cord and brain. The message to a muscle causing it to move comes from the cord and brain through a nerve. One message passes along the nerve and causes the muscle to contract once, and then relax. If another message comes before the relaxation is completed, the muscle contracts again, and does not complete the relaxation first. Consequently, for a muscle to remain contracted it must receive a rapid succession

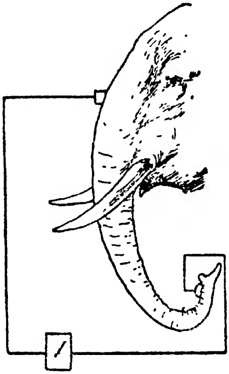


FIG. 114

of messages through the nerve. When a man stands still on one leg his weight is being partly supported by a group of steadily contracted muscles. Each of these is receiving messages through its appropriate nerve from the brain or cord at the rate of about fifty a second. One follows another so rapidly that all the muscles remain steadily contracted until fatigued. The Harvard Medical School physiologists have shown that in elephants the rate is about the same, forty-eight a second.

Jumbo was given a metal weight to hold, and wires were attached to the weight and his forehead, and portions of the currents passing through his trunk due to the twitching of his trunk-muscles on reception of nerve-messages could be directed through the galvanometer. Thus in steady contraction of muscles the steadiness is due not to an uninterrupted instruction to remain steady, but to a rapid succession of messages whose effects fuse together to cause an effect of continuity.

XLI

THE IMPROVED ORGANIC POST

When electric lighting systems were first introduced many people said the earlier system of gas lighting would rapidly be superseded. This has not happened, for the improvements in the use of electricity as an illuminant have helped to stimulate improvements in the technique of gas illumination. Something analogous has occurred in the evolution of the system for co-ordinating the actions of organisms. The development of the electro-chemical message system of the nerves has been paralleled by a development in the subtlety of the older system of causing actions by transporting chemical substances inside the cell, and later, in the passages of the blood-stream.

Everyone is aware how his heart begins to beat faster

on exciting occasions. There are two stimuli causing this, the nerve messages from the brain to the heart arising from information the brain has received from the external world; for instance, the appearance of a policeman, an attractive girl or a revolver shot; and the chemicals discharged into the blood-stream by glands which have also received notice of these interesting external events. In particular, certain glands near the kidneys are stimulated to discharge a small quantity of adrenalin into the blood. This substance has been synthesised in the laboratory, so there is nothing mysterious about it, but in the blood it passes through the heart and reinforces the nerve messages causing the heart to beat faster. The increase in the rate and strength of the heart-beat increases the supply of blood to the muscles and the brain, preparing the man for a special effort to escape from the policeman, to be active in the presence of the girl, to duck for cover and flee from gunmen.

The old Arabian physician, Avicenna, was aware, not of the existence of adrenalin but of the effects it helps to cause. One day a young man suffering from melancholy was brought to him. Many physicians had tried to diagnose his malady but all had failed. The young man continued to droop and his doting father was almost in despair. Avicenna gently took the young man's hand and bade him sit down in a quiet place. The father left them together. Though he talked of many interesting things Avicenna could not persuade the young man to speak a word. So still holding his wrist gently he discoursed on the various quarters of the city. When the name of one district was mentioned Avicenna noticed a slight jump in the young man's pulse. Continuing his discourse Avicenna gradually spoke of the main streets in that district. The name of one caused the young man's pulse to jump again. Avicenna wove his discourse around the characteristics

of this street and one by one referred to the numbers of the houses in it. Presently the young man's pulse jumped again when a certain number was mentioned. Recollecting the family in that house, Avicenna laid the young man's hand aside and sent him away, calling instead for his father. "Your son is in love", he said, and mentioned the name of the lady, her family, the street and district in which she lived. The overjoyed father soon conferred with the head of the lady's family and that happened which the son melancholily believed impossible.

Sudden emotional changes produce detectable electrical changes in the body. If a person's hands are dipped into jars of salt solution connected by wires to a delicate galvanometer the mention of anything exciting to him produces a deflection in the instrument two or three seconds later. The possible exploration of the personality by this effect is attractive, though difficult. The explanation of a person's interest in a crime, a person or an event may be very complicated and the mere fact of his interest misleading to those who discover it. His interest may be due to causes unknown to his consciousness, or to irrelevant accidental associations.

The thyroid gland in the neck secretes thyroxin into the blood. This substance is a very powerful help in the oxidation of sugar in the blood and a person with defective thyroid secretion is starved of sugar products for his growth and becomes sluggish and idiotic, a cretin. A dose of a third of a milligram of thyroxin a day is sufficient to keep him in normal health. It has been mentioned that thyroxin has been synthesised. There are four atoms of iodine in its molecule. Being such an important substance, many organisms cannot flourish without thyroxin and hence without iodine. If food is entirely deficient in iodine, men and animals will become cretinous. In Michigan, where soil and water lack iodine, it is impossible naturally to rear sheep. By

giving food containing iodine compounds to the sheep, the new industry of sheep-rearing has been introduced into that State.

The pituitary glands in the head secrete at least two secretions, one of which has a controlling function on growth. A person defective in this secretion tends to be dwarfish, while a person with too much grows into a giant. If an adult is afflicted suddenly by an over-activity of his pituitary gland he may rapidly grow several inches taller.

Another of the secretions, pituitrin, stimulates the womb and is sometimes given in child-birth to cause the womb to contract powerfully, and expel its burden more quickly.

The thyroid and the pituitary glands have a profound rôle in the control of growth. If a tadpole is given food containing thyroxin it rapidly turns into a frog, even if it is no bigger than a blue-bottle. The thyroxin penetrates throughout the body in the blood-stream and causes simultaneously those new processes of growth which differentiate an adult from an immature organism. The Mexican axolotl lives on the dry Mexican plateau and consequently searches for watery places and has become adapted to a watery life. If it is given just one small dose of thyroid it changes into a salamander, from a water to a land animal! (Plate XXVa). This change is conditioned by the pituitary, since the thyroid extract will not work unless it is taken from an organism with an intact pituitary gland. Here the inter-connection of glandular action is demonstrated. The effects of the secretions from the sexual glands are equally fascinating. When a person sees a sexual opposite, the eye and its nerve conveys the impression to the brain. If the brain finds this interesting it sends a nerve message to the sexual glands causing them to secrete into the blood-stream. The behaviour characteristic of maleness or

femaleness results. If the sex glands of a male rat are removed and replaced by female glands it behaves in a sexual situation like a female. Its latent milk glands may be stimulated to secrete milk and its general structure and appearance may become more female. Conversely, a female rat with male glands grafted into it will behave masculinely and attempt to copulate with females. The dependence of sexual characters upon glandular secretions is illustrated by the famous hen examined by Professor Crew. This animal normally laid eggs. Then its sex glands became diseased and the secretions consequently altered. It changed gradually into a crowing cock with comb, and became the father of chickens.

In the Middle Ages, crowing hens appeared occasionally, and sometimes were burnt as witches. The effect of the secretions of the sex glands can control a person's sexual personality, and to it must be attributed the femininity of some men, and the masculinity of some women, and perhaps the complex and sometimes unpopular personalities which seem to contain a remarkable mixture of both characters.

> "A whistling maid and a crowing hen
> Are neither fit for God nor men."

XLII

THE SENSES AND THE BRAIN

THE specialisation of cells in organisms has produced during the ages the mechanism of muscles, viscera and controlling nerves which constitute the bulk of the volume of the body. Even the skeletal structure is a cellular product produced by specialisers in the deposition of lime. Every part of the body consists of, or has been produced by, cells. The same technique of specialisation has operated on the character of those parts of, or

collections of cells which in the beginning had the greater share in the detection of the facts of the environment.

If a cell was to react to changes in an environment it had to possess parts sensitive to changes of various kinds, to changes in the chemical constitution of the sea in which it lived, to temperature, light, etc. When many-celled organisms had appeared certain of their cells specialised in detecting such changes. Some cells became sensitive to temperature changes, others to changes of light and sound. These vigilants of change necessarily became closely incorporated in the control system of the body, since action depended on the nature of the disturbances of which they apprised the body. They necessarily evolved in direct connection with the nervous system. So the tongue, nose, eyes and other sense-organs are directly connected by nerve-fibres with the nerve-cells of the cord and brain. When there is a noticeable change in intensity or distribution of illumination the eye is affected and a message runs along the nerve-fibres from the eye to the brain. If the brain finds the change of importance it may send out messages along nerve-fibres to the muscles, causing an appropriate movement. The receiving organs—the receptors—and the nerves and muscles must evolve in step.

Refined senses are of no use to an organism incapable of acting subtly, so crude senses and crude activities are associated. Water is a much more opaque substance and immensely more resistant to diffusion than air. In it light is absorbed by suspended matter, so even if a fish's eyes were very good it would not be able to see far. Consequently fishes have not, with some exceptions, evolved eyes capable of seeing clearly over a great range of distances. When fishes smell they detect directly molecules dissolved in the surrounding water. These molecules act on nerve-endings and the nerves convey messages to the front part of the brain. Fishes taste

often by nerve-endings spread all over the skin, so they can detect edible food even when it has no smell for them and is dropped behind their backs. The messages from the receptors for taste go to the hind part of the brain. The fact that the destinations of nerve-messages for taste and smell are different is an indication that fishes both taste and smell. Owing to water being a liquid molecules of substances diffuse slowly through it. A blind fish cannot detect a morsel of food one foot away until currents and diffusion have brought some of the odorous and the tasteful molecules to it. An animal living in air receives the notice vastly more quickly, since molecules move through air thousands of times more quickly than through water. Smelling in water and in air seem at first fundamentally different techniques. The first is so slow and the second so swift. When an animal smells in air it often snuffles. This is obviously done to pass more air containing the odorous molecules over the odour-detecting nerve-endings in the nose. It is difficult to imagine fish snuffling, so one wrongly assumes their technique of smelling is fundamentally different. The nerve-endings in the nose are not affected by the molecules if they are not damp. Consequently the odour-detecting membrane in the nose is always kept damp by secretions from a gland. The function of the moisture is to dissolve the odour molecules in order that they may react on the receptors for smell. This technique points to the evolutionary origin of our sense of smell. In spite of the superficial difference man's and fish's methods of smelling are in principle the same, and indicate the human technique of smelling has evolved from that of the fishes, and has been developed to suit animals living in air.

One of the most interesting cases of evolutionary development is exhibited in the history of the apparatus for controlling the posture of the body. Everyone will have noticed the white line along the side of many fishes

and have momentarily compared it, perhaps, with the Plimsoll line on a ship. This line marks the situation of a tube under the skin containing many sensitive cells. It is believed that the pressure of the water on the tube stimulates the cells so that the fish is apprised of changes in water pressure on its flanks and hence of its speed and direction of motion relative to the water.

Jelly-fish have organs which contain sensitive cells and little particles of lime. If the jelly-fish heels over on one side the distribution of the pressure of these particles on the hairy fibres of the cells is altered, and the cells are stimulated to cause a reflex movement to right the fish's posture. Some shrimps put particles of sand in their corresponding organs with their claws, and will use iron filings if supplied to them instead of sand. The filings can be caused to fall upwards by holding a magnet above the shrimp, and then they press the hairs of the cells upwards. The cells stimulate the appropriate reflex and the shrimp turns upside-down, and continues to live and swim upside-down so long as the magnetic field endures.

The white lateral line in the fish and the levelling apparatus in the jelly-fish and shrimp appear to suggest what the postural control organ in the very distant ancestors of humans was like. In fact, the balancing organ consisting of the semicircular canals (fig. 115) and the spiral tube of the cochlea are possibly the lateral line of a fishy ancestor which has shrunk off the length of the body and tied itself up in knots in the ear, within the protection of the skull. This interesting speculation involves a knowledge of the functions of the lateral line which still remains obscure. The base out of which the canals project contains limestone particles whose pressure against hair cells causes stimuli advising the brain of the posture of the body when it is steady in any position. One canal is horizontal and the other two are vertical but at right angles to each other, so they are aligned

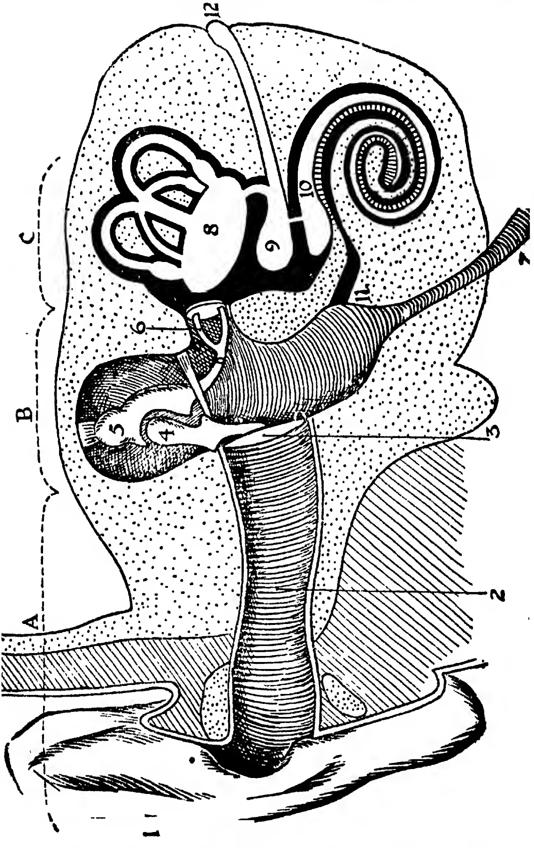


FIG. 115. Diagram of the Human Ear. (J. A. Thomson.)

according to the three dimensions of space. When the head is turned the fluid tends not to move, according to the principle of inertia, and presses against sensitive hairs in the canals. The ratios of the three pressures will inform the brain of the direction of the turning, and the intensities the rate of turning.

The other knot of tube, the cochlea, has been adapted to the task of detecting sound. When waves of air of certain frequencies fall on the ear-drum (3) they are transmitted through the lever apparatus (4, 5) to operate (6), which impinges on the fluid (in black) of the inner ear. The impulses in the fluid cause fibres in the cochlea to vibrate and notice of vibrations is received in the brain and interpreted as sound. The ear in man and the higher animals has been efficiently evolved to perform two functions, the detection of sound and of change in posture; one more instance of the extraordinary degree to which organisation is raised in the mechanisms of living things.

The physical differences between water and air account for much of the difference between fishes and men. An animal whose receptors were adapted to the slow heavy movements of water must have found when trying to live in the air the necessity for developing receptors adapted to its swift light movements and clarity. The release from the bondage of liquidity allowed these receptors to develop in the Protean air. The behaviour of a land animal has extra possibilities of complexity because air is subtler than water, and the difference between mind and matter as implied in the difference between the behaviour of the higher and the lower animals has been conditioned by the difference between liquid and gas.

People speak of mind and matter as of entities fundamentally different and without a common origin. There is a difference, but rather as that between air and water stuff manifested in two different kinds of state. What

men call mind is something which became prominent in organisms adapted to live in air.

The function of the receptors is to receive notice of changes in the environment and report through the nerves to the brain. Acting on the information the brain sends messages to the muscles, etc., causing the animal to behave in a more or less appropriate manner. Receptors and muscles do not use the same nerve-fibres for messages. Apparently messages will go along nerve-fibres in one direction only. In this respect the nervous system differs from a telephone system in which messages go along the wires in either direction. The nerves from the receptors to the brain are called afferent, those from the brain to the muscles, etc., efferent.

The most active receptors and hence those sending most messages to the brain will tend to require specially large exchanges in the brain to deal with the information received. Less is known of the localisation of these exchanges than might be expected. The brain is very sensitive and in many ways tends to act as a unit. If it is damaged, there are usually two effects, due to the actual damage, the destruction of cells; and that due to a faulty part in a highly complex mechanism. When a sparking-plug of an auto engine is defective the cylinder does not fire. Consequently the rhythm of impulses to the driving shaft is distorted and irregular vibrations are caused. The driver becomes aware of these and deduces the sparking-plug trouble. But in detecting the cause of the trouble he did not immediately see the tarnished points on the plug. He detected a functional disturbance in the whole machine. In a comparatively simple machine such as a motor-car a defect in a plug can often be deduced from a functional disorder in the machine. In an extremely complex machine such as a brain the interpretation of the cause of any disorder in behaviour is enormously more difficult, especially when it is not in

general permissible to experiment surgically on the brain. The physiologist trying to discover the locality of any brain activity is in the position of a motor engineer's apprentice who may never touch the machinery of a car unless it has already been wrecked. He has to wait in the garage until the remnants of some battered Ford or Rolls are brought in. He will rarely have the same make of car twice, and will never receive the remnants of two different cars which suffered quite the same kind of accident. The whole of his knowledge of the insides of motor engines will be derived from examination of defective machines. He will learn most in times of peak accident rates. This is, in fact, the case with the progress of knowledge of the localisation of activities in the human brain. In the Great War the brains of many men were damaged by fragments of shells and the injuries could be correlated with the disturbances of perception and action in the patient's behaviour.

Direct experiments on the brains of animals are permitted according to regulations which vary in different countries. By means of these and the mass of accidential evidence from human and veterinary surgical records and other more indirect sources of evidence, the localisation of many activities in both animal and human brains has been discovered.

The areas of the brain concerned with the reception of messages from receptors are (21) for hearing and (24) for vision (fig. 116). The sensations from skin and muscles are dealt with in the region (25). The parts which issue the orders for movement and control messages despatched to the tissues are (1) for the toes, (2) foot, (3) calf, (4) thigh, (5) belly, (6) chest, (7) back, (8) shoulder, (9) upper arm, (10) forearm, (11) wrist, (12) fingers, (13) neck, (14) eyelids, (15) cheeks, (16) jaws, (17) lips. The eyes are controlled by (19) and the tongue by (20). It is very interesting to notice how small a

region is necessary to deal with the mass movements of the body. The complicated control of seeing and moving the tongue require areas of the same order of size as the whole of the trunk. Evidently eyes demand a considerable brain apparatus for their control and the better the eyes the larger that part of the brain must be.

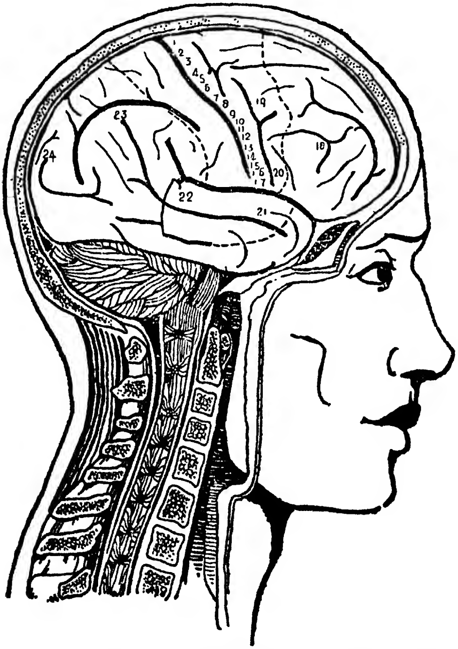


Fig. 116. Diagram of the Human Brain. (After Huxley and Herrick.)

Consequently, the eye-control areas in the brains of land animals should be relatively larger than those of animals living in water. This increase is strikingly evident, when the brains of animals representing an ascending scale of evolution are studied. The size of the area concerned with tongue control in man, that is, with the control of speech, shows what a complicated task it has to perform. Since speech and thought are often (not always !) closely connected, thought evidently involves large areas of the brain.

A consideration of the effects of damage to brains exposes the evidence for these localisations. The severe effects of the destruction of the whole of the top part of the brain, the cerebrum, are sweeping and are best seen in dogs. By a skilful operation the cerebrum can be removed from a dog's brain. Afterwards the animal behaves like a balanced automaton. It stands stiffly, and is unconscious of the environment. It cannot recognise food, and will not move towards meat placed in front of it. It will eat only when food is placed in its mouth, for the chemical nature of the food stimulates the reflex motions of eating. It can walk but does not avoid obstacles. If the lower part of the brain, the cerebellum, is destroyed the ainmal loses control of its balance.

Alcohol causes its characteristic effects by disorganising the operations of the cerebellum. Evidently the function of the cerebellum is to co-ordinate the various messages sent to the muscles and tongue by the cerebrum. If it is hindered by damage or drugs it cannot hold the balance between the various cerebral impulses to action. Each impulse gets its own way and is not rigidly compared and combined with the rest, so the subject tends to make a series of disjointed, too violent and enthusiastic actions. If the cerebellum had been able to perform its duty it would have toned down each impulse and blended it with the rest to produce a harmonious, controlled piece of conduct.

When both cerebrum and cerebellum are destroyed or put out of action, the body can still do a surprising number of things. It will move a leg to scratch away an imaginary fly and can still use the mouth and digestion for eating.

More detailed knowledge comes from the study of the effects of more localised faults. If a right-handed person's head is damaged on the left side, very many effects may be noticed. If the damage is great, his understanding and speech may be destroyed. If the damage is of the right side the effects are nothing like so serious. Evidently most of the work of thinking and speaking is done by one side of the brain, a most extraordinary fact. Why have two cerebral hemispheres if one does most of the work ? It is not so simple, of course, but the question naturally is asked. The nerve-fibres connecting the cerebral cortex with the body are crossed over near the top of the spine, so that the fibres controlling the right side of the body run to the left cerebral hemisphere, and vice versa. If the visual area in the left half of the centre is destroyed a man cannot see with the left half of either eye. Neither eye can see to the right. If the visual areas are destroyed in both halves of the cortex the man is blind, but if the damage does not extend beyond these areas he may retain his visual memory, being able to remember his friends and the world as they were before his accident.

If the areas next to the sensory areas are damaged the patient cannot co-ordinate his sensations. For instance, if the areas adjacent to the sight localisation at the back of the cortex are damaged the patient may be able to see separate entities perfectly but be unable to draw conclusions from their contiguity. In particular, he can see the separate letters of any word such as F I S H, but cannot associate the four letters to represent one thing, the entity fish. He cannot obtain *one* meaning from *four* letters. This defect is called "word-

blindness". The patient is often normal at arithmetic or algebra because in these techniques each symbol represents one idea. If he could have learned that F alone represented *fish* he would have been happy—but he cannot derive one meaning from four sights. If the areas adjacent to the hearing area are damaged a similar defect of word-deafness is caused. The patient hears individual sounds perfectly but cannot deduce one meaning from a group of contiguous sounds. He hears "con" and "ver" and "sa" and "tion" perfectly but cannot deduce from the four sounds the idea of conversation.

There are many degrees of these defects. Some persons become word-blind after a little mental fatigue. They will read a page of a book perfectly and then begin to spell out letter by letter. After a rest they will read another page perfectly, and so on.

XLIII

THE NERVOUS SYSTEM

THE structure of the nervous system explains at once various peculiar phenomena experienced by diseased persons.

Suppose a man is playing football. He sees the ball approaching. The rays of light travel from the ball to his eyes, stimulating the nerve endings at the back of the eye. A message runs along the optic nerve-fibre to the part of the brain specialising in reception of message from the optic nerve. This part of the brain hands on the information to many other parts of the brain: "Ball approaching". Among many other centres the message will arrive at the centre controlling the right leg. The brain as a whole, after having sent a message back to the eyes to discover the whereabouts of the opponents and has received a reply, combines this

second piece of information with the first, and allows the message to the right foot to kick the approaching ball to go through, and pass down the spine and nerves in the right leg to the muscles causing the foot to kick. If the second piece of information were of a different character it might check or inhibit the message to the right foot, for the brain might have discovered the player had better stand still and let the ball go by him to a colleague better placed for a kick. Even if the player takes no notice of the situation and just kicks the ball as

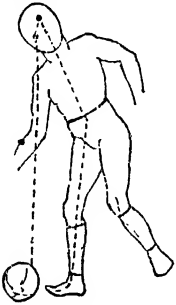


FIG. 117.

hard as he can without consideration, a message must have gone from his eyes to the sight-sense region of his brain, and then a message to the area controlling feet and legs. At least one message into the brain and one out. Now suppose for some reason the nerve-fibres carrying the message from the eyes to the brain suddenly snapped. The brain would never receive the message that the ball was approaching. The player would be blind. He could kick perfectly well if he knew the ball was approaching, but not knowing that he remains still. On the other hand, suppose the nerve-fibres from his

spine to his legs suddenly snapped. Though he could see the ball approaching perfectly well and send the nicest instructions down the nerves to the right leg, he would stay still, for the messages would never reach the leg muscles owing to the breakdown in the nerve-fibres; he would be paralysed. In general, blindness is due to a defect in nerves carrying messages into the brain; paralysis is due to defects in nerves carrying messages from the brain.

If the nerves carrying the messages from a sense-organ to the brain are destroyed, the brain receives no notice of anything affecting the organ. This seems trite enough, but the implications are remarkable. It implies that everything we call a "sensation" or a "feeling" is due to an occurrence in the brain. What we call a sensation of light is due to something caused to occur in the brain. If the nerves carrying messages from the eyes to the brain are destroyed the patient can have no new sensations of light, and if the nerves from all touch organs in the skin are destroyed nothing that touches him will ever cause him pain. Pins may be stuck in him and he will feel nothing. Yet we all talk of "tooth-ache", "eye-strain", "stomach-ache", "pains in the leg", etc. Everyone would assert that the pains he feels are in his tooth, eye, stomach, leg, or whatever is injured. They are not. The impression that the ache in tooth-ache is in the tooth is an illusion. The brain has an extraordinary property of being responsible for feeling the pain and yet representing that the pain is not in the brain but in the place where the tissue is damaged.

Normally the nerve carrying messages from the eye to the brain is activated only by light falling on the eye. Suppose it is activated by a stimulus other than light, what happens? A message ostensibly from the eye arrives at the optical reception area and is registered as light. The experiment can be performed by sending an electric current through the head so that it stimulates

the nerve endings in the retina and causes a message to go to the brain and be registered as a flash of light. The person is given electric shocks and interprets them as light. If the eye is closed and the eyeball tapped the patient sees flashes of light, and when he "sees stars" that is due to a message started in the optic nerve by shaking, and not by light falling on the eye (Plate XXVb).

The famous cases of men who feel pains in their wooden legs is to be explained in the same way. The fact is that a pain in a wooden leg is just as real as a pain in an ordinary leg. It is due to stimulations in the upper remaining sections of nerve-fibres which would have run from the various nerve endings up to the cord and to the brain. Sometimes little tumours grow on the ends of the nerves in the stump of the leg and the disturbance they cause is registered in the brain as a pain in the departed big-toe, or other tissue. Removal of the tumours removes the big-toe pain. Occasionally surgeons have difficulty in persuading a man whose leg has been amputated that he really has lost his leg. "But I can feel it", he says, and accuses the surgeon of having hidden it under the bed, or indulged in some trick of illusion.

If a man may be with difficulty persuaded that his leg has really gone after amputation, the necessity for care in postulating extraordinary explanations of strange phenomena is evident. A person seeing hallucinations may undoubtedly have sensations of seeing in his brain, for it is possible the nerve carrying messages from the eye to the brain has been given some unusual physical stimulus inside his head. It is not very much more to be convinced of the existence of a whole non-existent person as of the existence of a non-existent leg. People alleging they see ghosts may perfectly well experience the sensation in their brain. It is probably due to some defect in their system of afferent nerves and the associated sensory reception areas of their brains.

Seeing ghosts may be compared to the experience of a man whose telephone bell rings for no apparent reason. He takes off the receiver and says "Hello", and nothing happens. He goes back to his armchair by the fire, and presently the bell tinkles again. He goes to the 'phone and yanks off the receiver and says "Hello" sharply and then bullies the exchange, who know nothing of a call. Ultimately, the trouble is found to be due to an electric current leaking into his wire through a fault. So in the brain of persons seeing ghosts, nerve-currents normally going elsewhere leak into those fibres running to the areas of optical perception and stimulate the sensation of images of persons.

XLIV

THE STRUCTURE OF THE BRAIN

THE good business man or administrator usually works at a tidy desk. All documents for his consideration are brought from offices outside his room, and his informa-

FIG. 118.

tion is organised on a peripheral system. He avoids congesting everything around him. A similar principle is observable in the organisation of the brain. The files

of information are the brain cells, usually spread over the outer surface, so that the interior of the brain is clear for numerous lines of connection between cells in various parts. The top part of the brain in the higher

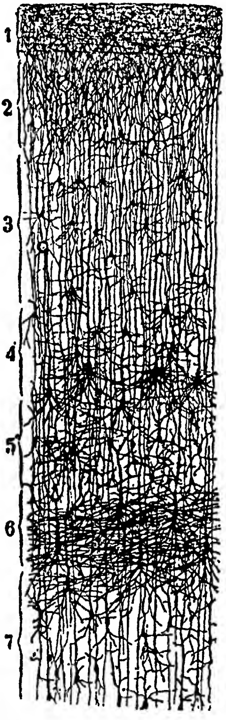


FIG. 119. Section of Cortex of an Infant's Brain. (Herrick.)

animals," the cerebral cortex, notably exhibits this principle of arrangement, for its surface is made of a mass of cells, while the interior is a mass of connecting nerve-fibres. The difference in constitution is marked by a difference in colour, for the surface is grey, while the interior is white. Besides having the layers of cells on the outside, the capacity of the brain is increased by a crumpling of its surface. The area is greatly increased, so that the number of brain-cells is greatly increased. The grey surface layers consist of millions of cells with innumerable fibre inter-connections. A counting of the cells in a small portion of the layer enables the total

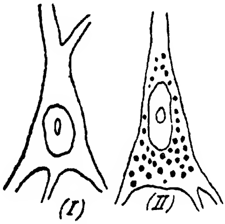


FIG. 120.

number of cells in the cortex to be estimated; there are between one and ten thousand million. The possibilities of inter-connections between such a number are prodigious enough to appear to us infinite, and are the material reality corresponding to the apparently infinite variations of the mind, the combinations of ideas and the activity of thought. The cells of the brain do not multiply during life. The newly-born baby has the full complement of cells for the whole of his subsequent life and even if he receives a Nobel Prize for his intellectual achievements he will not have increased his cellular equipment. The cells will have grown more complicated, and have begun to accumulate fat or

débris which in old age will have increased until they begin to deteriorate in action, and the savant's mind becomes feebler. After the cerebral cortex the cerebellum is the most prominent portion of the brain. It also has layers of cells on the outside surface and some groups inside, and large bundles of fibres connecting the cells with the rest of the brain. The cerebrum is concerned particularly with internal co-ordination. It is not, so to speak, interested in the organism's environment, and has no opinion to offer on the value of any action; it sees merely that the action ordered by the cortex is efficiently performed, as a sergeant-major sees that the

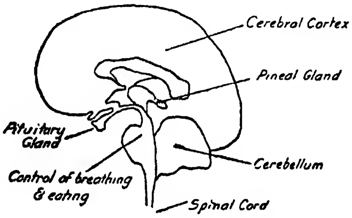


FIG. 121.

units of a battalion act together harmoniously. The colonel corresponding to the cortex has delegated the internal control of the battalion to his inferiors and is chiefly concerned himself with the operation of the battalion as a whole.

In the portion of the brain directly above the end of the spinal cord and next to the cerebellum, a broadening out of the spinal cord, are groups of nerve-cells and fibres concerned with the control of breathing and eating. The low position of these explains how persons with extremely damaged brains and decerebrate dogs can still continue to breathe and eat. The small pineal gland

is noticed because of its remarkable history. Descartes believed it to be the seat of the soul. Later research shows it is not a nerve-organ at all and is not part of the huge net of nerve cells and fibres which appear to be associated with mental processes. It is a gland exuding some secretion into the blood-stream. Evolutionarily it is the vestige of a third eye which lower animals such as reptiles sometimes have in the top of their heads.

Our distant animal ancestors had an eye in the top of their heads, but had no great use for it or found better ways of achieving the duties it performed. In the course of evolution the eye degenerated and became blind and finally was turned over to another job as a gland.

XLV

THE BRAIN MACHINE

The complicated behaviour of the higher animals is associated with activities in the brain and nervous system. Aristotle in about 300 B.C. believed the heart was the focus of the material activities associated with intelligence; when a man thought, his heart was the location of any physical activities associated with his thinking. Nearly two thousand years passed before this opinion was controverted by Vesalius. The great Italian anatomist announced that the brain and the nervous system and not the heart were the material associates of what is called the personality. His splendid discovery would have excused his fabrication of spurious theories of the mode of operation of the brain, but with superb scientific spirit he restrained himself from speculation. In 1543 he wrote: "How the brain performs its functions in imagination, in reasoning, in thinking, and in memory, I can form no opinion whatever".

Compared with what remains to be learned, know-

ledge of the mode of operation of the brain during intelligent activity is still extremely small.

This relatively small bit of knowledge is nevertheless absolutely considerable and suggestive. The most remarkable single contribution is from the Russian physiologist Pavlov and his colleagues. At first one would expect the knowledge of the physical operation of the brain to be much greater than it is. Later, when the complexity of the brain, with its many millions of nerve-cells and the possibility of an incredibly greater number of inter-relative connections between them is reflected upon, one wonders rather that anything systematic should have been established respecting its mechanism.

There is strong temptation to accept the opinion of those who believe the personality is directed by a free will. If this were true the operations of the brain, in so far as they were a correlate of intelligent behaviour, would be for ever inscrutable, since it is necessarily impossible to discover the laws governing a lawless will. In fact, if the will were free it is difficult to see why brains should exist. An organism possessing free will can have no use for any mechanism in the control of its behaviour, because its behaviour is uncontrolled. If behaviour were free and above control no control centre and therefore no brain would be necessary.

Muscles and the various organs of the body are controlled by messages sent to them through the nervous system. When a message goes down an efferent nerve the muscle at the end contracts; and there is excitation, action. Suppose that just as the message was about to leave the brain or spinal cord on its journey down the efferent nerve-fibre to the muscle, it was intercepted; what would happen? Nothing, apparently. Certainly the muscle would not contract. If an animal or any living unit is given a single stimulus in general it gives a single response. If a fly tickles a dog's side, the message

goes from the nerve-endings in the neighbourhood to the spinal cord and directly through the centre for controlling the scratching mechanism, whence messages directly go to the various muscles operating the scratching leg. Now suppose that owing to some natural or acquired peculiarity in the dog the message from the tickling spot splits up into two parts on reaching the spinal cord. After pursuing different routes they approach the centre in the cord controlling the scratching mechanism from different directions and obstruct each other. Having obstructed each other the scratching mechanism will not receive any instruction to operate, and the dog will not scratch the tickling spot. Though there has been no leg movement, there has been some activity in the nervous system. The process is clearer when two simultaneous stimuli are considered. Suppose at the moment the fly alights on the dog's side, a needle is jabbed into the foot the dog would not use to scratch with. Two messages reach the central nervous system simultaneously, the natural reflex reaction to one being to lift one leg to scratch with, and the reaction to the other being to pull away the other foot from the needle. If both reflexes operated at once the dog would fall down. In fact, the pain reflex obstructs the tickling reflex, so the message from the needle pain must have intercepted in the cord the message from the fly tickle and prevented it from operating the scratching reflex. This possibility of a stimulus not necessarily calling forth a response is fundamentally important. The effect is called inhibition. It is a positive effect just as the straight-forward reaction of scratching is positive, but does not go beyond the cord and brain. Thus there are two possible reactions to a stimulus, excitation or inhibition, ultimate action or non-action. In practice all reactions are mixtures of one type more or less diluted with the other.

Pavlov has succeeded in interpreting much of the

activity of the brain in terms of excitation and inhibition. His peculiar success was due to his perception that degrees of excitation and inhibition could be detected and measured. It is not difficult to see in a general way that behaviour can be explained in terms of a combination of excitation and inhibition, but it is difficult to discover manageable forms of action controlled by the brain, the existence and strength of which can easily be discovered and measured.

Pavlov's method of investigating the conduct of the brain came to him in an inspiration which reminds one of Napoleon's into the conduct of war: "An army marches on its stomach". Pavlov observed that the activities of a dog's brain are manifested in its stomach, and in a remarkably manageable form.

During his investigation of the secretion of digestive juices into the stomach, Pavlov noticed how much so-called mental activities affected the kind and quantity of the juices oozing from the glands into the stomach. The mere sight of the food influenced the secretion, and the various juices came into the stomach in quantities which made a special mixture suitable to the nature of the food. It was as if the dog had said: "Ah! that approaching cereal, I must have plenty of suitable juices ready to digest it", or: "That is meat, I must have my special stomach mixture for meat ready". These variations indicated that the higher parts of the dog's nervous system including its brain were influencing the composition and quantity of the digestive juice mixture in the stomach. Pavlov saw that the measurement of the rate of secretion of digestive juices might be made to reveal information of what was going on in the brain. Then he remembered the happy fact that not all digestive juices are discharged in the stomach: there are the secretions of saliva into the mouth. So he decided to make mouth-watering reveal the operations of the brain!

Having made his digestive investigations with dogs, he decided to continue with the same material. The brain of the dog is much simpler than the human but with its main features. By confining himself to dogs, he made the data of investigation simpler and easier to control, since dog-life is comparatively simple, and dogs have no social traditions which might prevent them from being used as material for tedious and peculiar experiments.

XLVI

THE DOGGY MIND

The dog stands on a small table in a sound- and light- and in fact stimulation-proof chamber. Three comfortable supports keep him steady. The duct from the salivary gland is arranged to discharge its juice into two

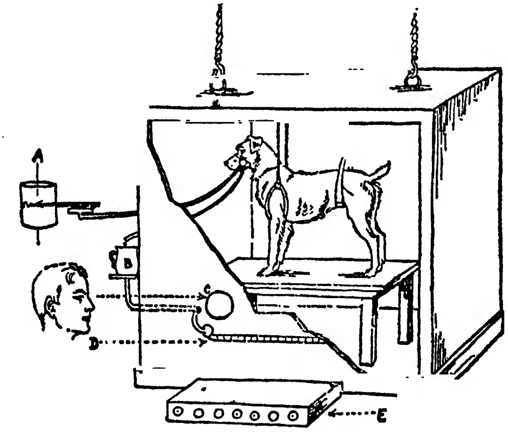


Fig. 122.

fine tubes instead of into the dog's mouth. These tubes carry the juice to two measuring apparatuses: A for measuring the rate at which the saliva is secreted, and B for measuring the quantity secreted.

To study the dog's brain machinery Pavlov has only to manipulate objects of food interest inside the chamber and see what happens. Almost any object can be made to signify food. For instance, in the Castle Moat at Wells in England there are some swans who pull a bell at 4 p.m. every day for food. The ducks in the moat spend a good deal of time during the day jumping out of the water trying to reach the bell-pull, easily accessible to the long-necked swans. They have all learned that the bell-pull is significant of food. In the same way a dog licks his chops, and salivates when he hears the cook's footfall outside the door, bringing his meal. He does so before he sees the food—in subjective language he knows the footfall means food.

If the cerebrum is surgically removed from a dog's brain, these reactions do not occur. Evidently the dog's intelligence depends on the activity of the cerebrum. When that is absent the dog is unable to recognise food. It eats only what food is placed in its mouth and the pressure and taste of it inside the mouth stimulates the eating reflexes to function. Newly-born baby dogs also are unable to recognise food. They do not understand meat is a food until they have eaten it several times, perhaps in imitation of their mother. Once the meat is in their mouth it stimulates the eating reflexes. Later, the puppy recognises meat at sight and waters his mouth. Evidently the cerebrum which at first had never had the experience of acting in relation to meat, later had a trace of former activities regarding meat, and so caused the salivary glands to secrete at the appearance of meat. Experience causes a dog to employ its cerebrum in the control of its mouth-watering.

Pavlov calls the automatic reflex of eating and salivating stimulated when food is placed in the mouth, an unconditioned reflex. It is not dependent on the cerebrum because it appears in decerebrate dogs, and in baby dogs whose cerebrums have never been used in that connection.

He called the licking and salivating reflex activated by the cook's footfall, the sight of meat, of a bell, etc., a conditioned reflex. The unconditioned reflex of eating has been conditioned to act on the occurrence of an event such as light or sound which has in itself nothing whatever to do with food. Those parts of the cerebrum utilised in the interpretation of sound, of light, or touch, etc., are active when a dog's mouth waters at a sound, light, touch. Therefore the rate and degree and manner of mouth-watering must be related to the nature of the activities of these parts of the cerebrum.

Conditioned reflexes are established by presenting a sensation to the dog immediately before giving it food. For instance, a metronome ticking a hundred ticks a minute is started for a certain period, and then food is given. Presently the dog begins to salivate as soon as the metronome is started. After a number of trials the eating reflex has been conditioned to react to a 100-a-minute metronome beat, and gives always about the same number of drops of saliva at the same rate as soon as the ticking starts.

Now what happens if the metronome is set to tick 50 times a minute? The dog does not salivate when the metronome is started. The sound-receiving part of the cerebrum has not associated a 50-a-minute ticking with food. By increasing the ticking rate gradually, it is possible to determine the power of a dog's brain to distinguish between rhythms. At 97 to the minute, salivation appears, proving that the dog can distinguish between a rhythm of 96 and one of 100 to the minute.

This power of rhythmic discrimination greatly surpasses that of the best human musicians.

If a circle is presented to the dog before food, its brain learns to cause salivation at the appearance of the circle. If a very elongated ellipse is presented, there is no salivation. The ellipse is gradually made rounder, until the dog mistakes it for the circle, and salivates. The ellipse is then nine units long and eight broad. When the limit of discrimination is reached the dog shows signs of mental distress. It howls at its problem in conic sections, and may even have a general nervous breakdown in the attempt at solution. Bromides serve to calm his excited nerves, as effectively as in any overwrought schoolboy examinee.

Pavlov confirmed Galton's demonstration that dogs have a greater range of hearing than humans. They hear the note of a Galton whistle which is too shrill for human hearing and can hear lower notes than we. (A dog will answer a blast on a Galton high-pitch whistle and come running to his master, when no person standing by can hear any sound at all). The same technique demonstrates that dogs have a poor sense of colour but can discriminate shades much better than humans. They can tell the difference between two shades of grey quite indistinguishable to human eyes.

Smell is the most interesting sense for investigation in dogs. The area of brain devoted to smell-impressions is relatively very large in the dog and small in humans. The world of smell is therefore particularly poorly known by us, and it would be interesting to learn something of the character of the dog's highly-developed smell-world.

Unfortunately, to determine what is a standard smell is difficult. The essence of Pavlov's technique is quantativity, that is, accurate definitions and measurements of all features in his experiments. Until smells of standard quantity and strength can be produced, an accurate analysis of the smelling powers of dogs cannot be made.

XLVII

INHIBITION

WHEN a dog has been trained to expect food after a slight electric shock, its mouth salivates the same quantity and at the same rate each time the stimulus is administered, if food always follows the response. If the stimulus is given, but no food follows, the salivation decreases until after a number of experiences the dog ceases to salivate after the stimulus. He apparently has learnt to take no notice of the stimulus even if in the past it meant food. Thus the stimulus now draws no response. The messages through the nerves from the place of shock to the brain have not proceeded on to the nerves going from the brain to the salivary glands. They have been obstructed, or inhibited, while in the brain.

The necessity for the technique of inhibition is clear, for if an organism reacted to all stimuli it would always be in a chaotic condition. Inhibition is, as it were, what shapes excitations into harmonious actions. It corresponds to the principle of natural selection in the society of growing organisms, weeding out and suppressing those inharmonious with the rest. Things destructive of inhibition such as nervous disease, or drugs like alcohol or strychnine, destroy the balance of the organism and reduce it to a chaotic plunging or a contorted mechanism.

When the dog has been trained to salivate after an electric shock, and this conditioned reflex has been extinguished later by not giving food after the stimulus, the brain-centres concerned with the sense of touch have inhibited the customary message from that part of the brain to the salivary glands. Pavlov noticed that this inhibitory process originating in the touch-centres

of the brain had a tendency to spread to adjacent centres, so that other activities besides a trained tendency to salivate after this kind of electric shock become inhibited. The dog became drowsy, and if the inhibitory tendencies of its brain were strong, it might fall asleep on receiving the shock, and commence to snore! The tendency of people to fall asleep over books or yawn over boring tasks is due to a similar mechanism.

Pavlov explains sleep as a wide spreading of inhibition in the cortex. Most of the stimuli falling on the animal reach the cerebrum and interfere with themselves or each other in such a way that no action results. His experiments suggest there is no such thing as pure waking and pure sleeping. At any moment, more or less of the centres in the cerebrum are inhibited. If many are inhibited the animal is asleep. If one or more is active and dealing with incoming stimuli with a view to further action the animal is awake. Thus the mother nursing her baby who hears its slightest movement in the night is not wholly asleep, only her brain centres for sight, touch, etc., are inhibited, not her centre for hearing.

Between all the stages of ideal entire waking, and ideal entire sleep when the cerebrum is completely inhibited, there are many grades of mixture. When the mixture of excitation and inhibition in the brain is of unusual constitution the animal shows unusual behaviour. For instance, some of Pavlov's dogs fell into trances. After receiving the stimulus the animal suddenly became stiff and still on his stand. In this condition the centres in the cerebrum were inhibited so that no notice was taken of most incoming stimuli, but the lower centres in the cord and brain were not inhibited, for they kept the animal in balance and erect. This is the condition of hypnotism, and is brought about by subjecting the animal to stimuli whose normal responses have been extinguished by lack of reward,

so that they produce an inhibiting effect. Stimuli whose meanings have been destroyed and have therefore become senseless are those which tend to hypnotise. Hence the meaningless passes of the hypnotist. The patient's brain can make nothing of them and the concentration on nonsense and therefore insoluble problems gradually inhibits parts of the brain until the condition of hypnotism is induced.

Pavlov and his colleagues hope to refine these experiments by reducing the area of inhibition so that the hearing centres are left uninhibited. If that could be done the dog would presumably be suggestible and when put in a trance would obey spoken commands.

Inhibition is due to the splitting and interfering of a message from a receptor to the cerebrum. In decerebrate dogs inhibition is greatly reduced. The animal will continue to give reflex responses, or take notice of stimuli which have lost their meaning, or are meaningless. Every time a sound is made the animal lifts and turns its head to investigate. This response is not dependent on the cerebrum. A dog with intact cerebrum soon learns to ignore sounds, not followed by significant action. Thus ignoring stimuli is a positive process, an activitv in the highest part of the brain. The fixed inhibited expression of boredom is due to a positive activity in the cerebrum. Perhaps this is why boredom is so tiring. The discovery has great industrial interest. It suggests boring work is exceptionally tiring and liable to make the operative unhappy. High wages cannot alter the nature of boring work. They may act through the fundamental reflexes of self-preservation as a stimulus which overbears the inhibition caused by monotonous tasks, but though they conceal the inhibitory reflex they do not destroy it.

Concentration is revealed as nothing more than a scattered sleep. In deep concentration on a problem

the unengaged centres of the subject's brain are inhibited. He becomes oblivious of the passage of time, of noise, of hunger. In spite of strong excitation of some centres others are inhibited or asleep. When Thales fell into the ditch during his meditation on the stars he was really walking in a fractional sleep.

Sleep is revealed, then, as a positive activity in the brain caused by stimuli flowing into it. We may suppose that ordinarily most of these stimuli come internally from fatigued muscles, but they may come from external stimuli which prove to be monotonous for the animal. Sleep is not an absence of activity, a draining away of energy from the brain. It is an organisation of energy to prevent the muscles and tissues of the body being used for a period, so that they can have time to repair loss of fat and tissue through use. But it is not necessarily associated with muscular fatigue. Muscular fatigue is only one of many stimuli capable of inducing sleep, though it happens to be the one most commonly operative.

During the thirty years of investigation into the activity of the cerebrum of dogs Pavlov has accumulated sufficient data for a classification of their nervous systems. His scheme is similar to Hippocrates' classification of human temperaments. Dogs can be described as choleric, sanguine, phlegmatic or melancholic. The choleric show strong excitation; a small stimulus causes a large response. In difficulty they cannot inhibit their actions and lose control, showing temper. The other extreme, the melancholic respond badly to any new stimulus, they become inhibited, shrink against a wall and creep away with their tails between their legs. The lack of active response due to inhibition is misleading, for the casual observer assumes the dog slinks away because it cannot take in the new situation, and is stupid. Experienced school teachers are aware that the

brightness and activity of the choleric excitatory type often prejudices the casual observer in their favour. But this type being under-inhibited has difficulty in learning, and tends to exploit the brightness of personality in its favour. Its peculiarity is best employed where swift action is necessary. In business management, the army, journalism, etc., swiftness is more important than perfection of response, and the choleric excitatory types are happiest in these professions.

The over-inhibited animal has often great powers of discrimination. If it can be given stimuli whose responses are not smothered by inhibition, it is sometimes capable of very subtle behaviour. Pavlov had an astonishing instance of this in a bitch so inhibited that when the kindliest approach was made it shrank and crept away. For months the experimenters tried to find some stimulus to which it would learn to respond, and give a conditioned reflex, but without success. She was nearly given up as hopeless. In the end they did manage to persuade her to respond, and afterwards she learned new reflexes with unequalled speed. In honour of her superiority in cleverness over all other dogs in his experience, Pavlov named her "Brains". The extremely shy inhibited type of person may prove to be the best of learners. He may indeed learn an artificial aggressiveness and change from a retiring to an apparently public personality. The complex inhibitions which so hampered him in the first efforts of learning serve him later as a powerful critical ability. Such is the type which learns hardly, because it is too critical and sees too clearly the difficulties. The swift learner is often under-inhibited and is facile because the stuff in his brain is too easily excited.

In his sublime investigations Pavlov commences from the fact that the brain is made of nervous matter fundamentally similar to all other nervous matter, he assumes that the stuff of the brain responds to stimulation as

any other nervous stuff so responds. The matter of the brain is excitable. From this fundamental quality of brain-stuff, the phenomena of inhibition are explained as obstructions or interferences of an excitation with itself. From the concepts of excitation and inhibition concentration, sleep, boredom, alertness, hypnotism and neurosis are in outline seen to be deducible. Pavlov does not require to incorporate a single mental concept in his description of the phenomena characteristic of intelligent behaviour. His work suggests the possibility of an objective description of the behaviour of the higher animals. The whole of the behaviour of man and all other organisms is capable in the ideal of being described entirely in terms of excitation and inhibition. Human behaviour to the objective observer is in principle completely describable in these terms. The human brain is probably too complicated for its description ever to be elaborated fully, though the assumption that it is incapable ever of knowing all knowledge is too easily made. If the universe is finite and the human brain is finite, all possible relations between them cannot exceed a finite number, so that the total quantity of possible knowledge is finite and knowable. The novelist should attempt to depict a world whose inhabitants knew everything there was to be known about it and themselves, and who lived therefore always within a finite cycle of possibilities.

XLVIII

APES

The races of apes and monkeys are slowly dying. They are possibly rather degenerate descendants of their ancestors, and the ape-like ancestors of man were of a type superior to them. But apes sufficiently resemble man's primitive ancestors to indicate what they were like.

In spite of a vast amount of observation of apes so admirably summarised in Yerkes' great book, there have been few exactly performed investigations of the mentality of apes. Those of Mme. Kohts, of Moscow, and Professor Köhler, of Berlin, are particularly notable. All of Mme. Kohts' experiments were made with one chimpanzee called Ioni. Her work is a beautiful demonstration of what ability can do with little material.

Mme. Kohts made a profound investigation into the perceptive ability of her chimpanzee by training him to match objects presented to him. She sat at one side of the table and Ioni opposite. She presented him with strips of coloured material, and Ioni had to pick out from a number one that matched. If he succeeded he was immediately allowed to play games of chasing, wrestling and catching. These seemed to give him his greatest joy. He was not punished if he failed, except that he was not allowed at once to be free to play. By systematic trials Mme. Kohts demonstrated that her chimpanzee could discriminate between thirty colours. In her experiments six were shades of red, four orange, three yellow, three green, two sky-blue, three blue, six violet and three purple. He could distinguish twenty differently coloured objects from a jumbled pile, and he could distinguish pairs of these colours. He could distinguish drawings of objects and letters, figures such as circles, ovals, twelve-sided polygons, octagons, pentagons, squares, rectangles, triangles, rhombuses, trapeziums and sectors; solid bodies such as spheres, cylinders, cones, cubes, various pyramids and prisms, and simple combinations of plane figures. He distinguished between heights varying by seven millimetres, and intervals of twenty-two millimetres and thicknesses of five millimetres. Smaller objects were distinguished more easily than large.

She writes that these experiments show the chimpanzee

is capable of complicated exact and fine visual perceptions comparable with those of a human child of corresponding age and far better than is necessary in its natural life. He finds the first notion of identity between two objects difficult, but once he has it recognition is quick if at all. He is very quickly tired and finds the notion of similarity very difficult. He can abstract colour from size and shape, being able to perceive the resemblance between bodies of identical size and shape but different colour, and he can abstract shape from size and colour. More difficult abstractions such as counting he could not achieve (Plate XXVI).

In his experiments, Köhler exploited chimpanzees' desire for food to expose the quality of their intelligence. He placed food beyond their reach and left various implements in the cage for the animal to assist himself with. They found out how to use sticks to knock down suspended bananas. They piled up boxes until they could reach the bananas, and they understood that bananas beyond the cage but with pieces of string attached could be drawn into the cage if the string were accessible. Some chimpanzees discovered that parts like those of a fishing rod could be put together into a long pole which would serve to reach the bananas.

Though they could perform these feats they showed no insight into the laws of mechanics. They never could learn that a ladder must lean against a wall and not be pushed up vertically, if it were not to fall over when climbed. They could solve problems only when all the materials were in sight. They rarely searched for a suitable implement not before them. This fact indicates that the chimpanzee has little power of calling up images of things it has previously used, its visual memory is operated only by the appearance of the thing itself or something like it. This is proved also by the social behaviour of chimpanzees. They love company and

are keenly interested in the behaviour of members in the herd and in sight. But a member of the herd out of sight is soon forgotten. A chimpanzee mother is most attentive to her baby and will cherish it for days even after it is dead. If the corpse is taken away she soon forgets all about it.

The activities of apes are in general very direct expressions of emotions. The range and character of ape-emotions is demonstrated in Mme. Kohts' wonderful photographs of Ioni. Here is an emotional expressiveness near to the human (Plate XXVII). Though apes have no language, that is, word-sounds as symbols of things, they have a wide range of sounds for emotional expression. Köhler describes the remarkable quality of the herd-cry against an evil-doer. He says it has an alarmingly reministic tone of disapprobation. Unfortunately it is raised over the slightest misunderstanding, as over the greatest crime, and the apes that saw nothing and knew nothing of the occurrence were just as violently disapprobative as the others; a phenomenon too familiar in other realms.

The reaction of chimpanzees to strange animals is extremely interesting. Köhler's apes were terrified by the appearance of cows and camels, and the apparitions acted like a purge. Even more interesting, the apes were terrified by grotesque toy animals with goo-goo eyes. The apes piled themselves up in the most distant corner of the cage and struggled to bury their heads as deeply as possible in the struggling mass away from the terrible object.

These facts suggest the necessity for care in the gift of grotesque dolls to children, and reveal perhaps a method of discovering why strange masks and effigies are so important in the rites of savages. Köhler found the apes were terrified when he put a Cingalese mask over his head.

The demonstration of the emotions of jealousy was beautifully made by baboons in Mme. Abreu's great collection of apes in Cuba. One always hid is wife when any man approached, but did not trouble to conceal her from women. Mme. Abreu brought a Catholic priest to see him, to observe whether he would mistake the priest in his cassock for a woman, but apparently he was not deceived.

Mme. Abreu had an adult male chimpanzee who fell in love with a fair-haired kitchen maid. To save the girl from embarrassment one of the assistants fastened a screen over the kitchen door. This assistant had previously been very friendly with the chimpanzee, but some days later he was attacked viciously. The ape afterwards never could look him in the eyes again.

The apes are emotionally close to humans. Their deficiency is in intellect, and this weakness is allied to their inability to summon images in their minds. Not being able to raise these images they cannot meditate and reason much. Man's superiority is due to the capacity of his intellect, which is directly related to the superior size and complexity of the highest part of his brain, the cerebrum. When stunted in intellect man is an emotional being almost indistinguishable from an ape, which is worth consideration by those tempted to depreciate the intellect.

XLIX

THE MIND

THERE is no direct evidence whatever that life exists except on the Earth. In the gigantic extent of the stellar Universe there is to us virtually no evidence of life. Perhaps the oxygen in the atmosphere of some of the planets indicates they bear life, but apart from this we have no reason to believe life exists except on the Earth,

and merely on the surface layers of that. Those who argue that life is a characteristic of all things and that the human mind has evolved from an element of mentality inherent in all matter have to explain why life should appear on such a trivial scale. As A. D. Ritchie has finely said: "If the seeds of life occupy all space and time, why are their flowers so few and brief?"

Those inclined to exalt the human mind too much should consider that question.

Since we all carry, or are supposed to carry, minds about with us, one would expect knowledge of the mind to be the largest of all branches of knowledge. In spite of our profound belief in the existence of our minds we have very vague notions of what they are like. Nothing would seem easier than to sit down and consider our own minds. But the results of such investigations have been so unsatisfactory that some distinguished psychologists doubt whether mind, or at least consciousness, exists. Though mind is difficult to define we all believe we know what we mean by it. The man who considers his decision to go to the sea for his summer vacation will explain how he thought of various places and chose to go to a particular one. He interprets his own behaviour in mental terms, thinking, considering, deciding. A physiological observer would describe the same piece of behaviour in quite other terms. He would report that his friend's fatigued nerves had sent messages to his brain which stimulated old nerve-traces made in similar situations in the past. These old traces on being activated sent messages to the muscles which manipulated his legs in the direction of the tourist company's ticket office, and so on. The event of a man's visit to the seaside is described by himself to himself in mental terms, but others describe it in material terms. Thus mind and matter seem to be different aspects of the same reality. They are exclusive

because the aspects of one thing from two points of view are necessarily exclusive, but each is logically coherent because each is a view of one whole thing. According to this idea a man's brain and his mind are different aspects of one reality.

So much for the connection between matter and mind.

In order to find out what the mind was like, men in the past sat down and introspected. The very act of concentration made the view of the "inner eye" much more static than it actually is. Examining this static event in the mind, men saw various prominent parts, sights, sounds, smells, etc., into which the event could be analysed. Consequently the mind came to be conceived as a construction out of small unchangeable parts, bits of red, snatches of sound, traces of flavour. The early introspectionists found a static quality in the mind, and a definite furniture of sensations, images, etc. The concentration on these evident entities caused them to overlook the possibility of there being other well-furnished rooms in the mind, and that at any moment the furniture in the rooms out of sight might have more influence on the behaviour of their owner than the evident furniture. Thus direct introspection failed to reveal two outstanding qualities of the mind, its dynamic fluidity and the fact that at any moment only a small part of its furniture is apparent.

The chief activity of the mind, we like to believe, is thinking. It is almost exact to assert that apes can think only when the objects about which they think are in sight. With them the things with which thinking is done exist only when the thing thought about is there. This means that an ape's thought of a stick is something which is in his mind only when he sees the stick before him. In primitive thinking the sight or the sensation of a thing is similar to the thought of it. Beginners like to have visible objects before them to think

with: that is why teachers draw diagrams on the blackboard. At a more advanced stage the thinker can dispense with the immediate sensation of present objects and work with the images of them. He can call up images in his mind from his memory and think with these. Engineers particularly tend to experiment with images in their minds, and artists also. In still more advanced stages of thought, images are dispensed with, as in the higher mathematics. Thoughts appear to be representations in the mind of things. In early forms of thinking (not by any means therefore the least important) thoughts are pictures of these things, later they are remembered pictures or scraps of parts of pictures, and as the thinking becomes more abstract the pictures or images become less important, until they appear rather as disjointed and not very relevant flotsam on the surface of a rushing stream of mental activity. At a later stage the relics of imagery disappear and the stream of abstract thought flows on, invisible.

If thoughts based on sensation are a necessity for mental activity, animals lower than apes cannot be said to have minds which work. Such animals do not seem to be able to handle pictures in their minds and discover relations between them, e.g., that one stick will fit into another. They have pictures in their minds, but each exists without relation to the others. Each picture has a pre-eminently emotional meaning and the animal is capable of realising the emotional meaning of two mental pictures even if he is incapable of seeing relations between the two pictures. Hence one mental picture, say of a tiger, gives him fear; another of his master, affection, and so on. The animal does not attend to what the other animal or man is like, but to the emotions these raise in him. This sort of thinking not of things but of the emotions these things raise, is the most primitive of all forms of thought. Humans fall back

on it very much, as, for example, when the lady says: "Mr. So-and-so gives me a funny feeling", she is considering the emotions that the man raises in her, not the nature of the man. But it often happens that this primitive machinery produces in individual cases better results than the application of more advanced methods of thought. The lady observes the man and the sensory centres of her brain receive messages of his appearance, inflexion of voice and movements. The disturbance in the brain resonates with the traces left from previous experience of unpleasant persons, and messages leave the brain to the organs so that a feeling of discomfort ensues. The disapproval has not arisen from an analysis in thought of the appearance and behaviour of the man.

Emotional responses are at the basis of language. The animal cries according to the emotions the appearance of things raise in him. If he cannot proceed beyond emotional representation of things, he can register only the feeling these things raise in him, not the characters of the things. For instance, he registers tiger as terrible, not as striped. Similar processes occur in the infant up to about eighteen months. The cries he makes are emotional registrations of his responses to situations. Suddenly the child begins to increase its vocabulary and demands to know the name of everything. He has switched over from emotional representation to objective description, he now utters sounds representative of the characters of the things, the word "chair" is learnt, for instance, and everything like a chair is called "chair." He is perceiving the objective similarities in things. The infant commences that marvellous rushing pursuit of knowledge which initiates him into the use of language. In a short period all the fundamental words of the language of the country and class in which he lives are sunk into his mind, not only the bare words

but the peculiar sentiments and pronunciations associated with them by the members of his social environment. He swiftly and deeply learns a technique of communication which is a product of unconscious evolution. The evolution of language has been almost as unconscious as that of an embryo. He grasps, necessarily without reflection, this fascinating but gnarled product of evolution, neither he nor his relatives and teachers considering at all whether the technique of communication he is learning is modern. He is in the position of a person who has just discovered he can ride a bicycle and rushes off to buy the first he can find, irrespective of whether it is new or of the latest design. It is a bicycle and gets him along somehow, that is enough. He takes it, with all its defects. The language he learns is the unconsidered end-product of an evolution from the sound-communications of ape-like ancestors. The immemorial words change less quickly than the entities they represent, until to-day we find words are often extremely misleading assistants in complex thinking. A colossal quantity of philosophising upon every side of life is entirely vitiated because persons use words quite unsuited to describe the things they are discussing, as if men must always sculpture with a hatchet because that was (perhaps) the first instrument used for the purpose. The importance of these problems has been emphasised by C. K. Ogden, who demands and has initiated a fresh study of the fundamental nature of language to reveal how it may be improved, or at least that men should understand the nature of the verbal tools they use. The defects of language are revealed by the inventions of algebra. In mathematics where the margin of permissible vagueness is usually small, the clumsiness of traditional language was too great to be borne, and a new, more appropriate one was invented, still semi-unconsciously, but enormously more con-

sciously than the traditional language has been. Ogden cites the immense importance of the words "good" and "bad". These are learnt in the cradle to apply to things "permitted" or "not permitted". Many years and often lifetimes pass before the person inquires "permitted by whom, and why?" Not having considered why some things may be good or bad, nothing happens in his mind except a feeling of goodness or badness when the words are applied to a thing or event by one of his social herd. He is no better than the ape who "feels bad" because a member of his herd has emitted a cry of discomfort. Wonderful though our partly subtle and partly clumsy language is, the majority of people operate it as if it were little better than a collection of ape-noises. They utter a large variety of sounds but do not realise that this does not necessarily imply there is a corresponding large variety of thoughts behind it. Much of our conversation and discussion is that of somnambulists, somnambulists of the intellect talking in an eternal intellectual sleep.

L

EMOTION

A MAN's character depends on his emotional qualities, and these depend on the nature of his nerves and glands. Successful action is rarely accompanied by strong emotional feeling; for instance, a confident golfer suffers much less than a diffident in a golf competition. It is well known that a "steady temperament" depends on "nerve", and some men are particularly good "big-match" players because they do not (as the majority) play less well under distracting conditions. An accepted lover is much less agitated than an unaccepted. Emotions seem to be the accompaniment of unsuccessful actions

or difficult situations, the warning of the organism to make a special effort to solve the problem.

A man is confronted by a burglar. He is instantly excited and he tends to think more clearly or confusedly, and certainly more actively. Describing the situation in physical terms his heart is stimulated to beat more quickly both by nervous messages and the secretion of adrenalin into the blood. What to his mind is an emotion to his body is a quickening of tempo. The same physical changes are demonstrated by the psychogalvanic reflex, which will detect a difference in a man's physical condition corresponding to the emotion in his mind when he sees a beautiful picture.

Strong emotions of pleasure and success never last long. This suggests they have to do with the removal of a strain in the mind. As everyone knows, familiarity with the greatest success always breeds contempt. The successful come to realise they were born with capacities sufficiently good to be successful, and that their achievements were not particularly creditable. It was probably no harder for Shakespeare to be Shakespeare than for George III to be George III. Einstein has said that his discoveries came without exceptionally severe mental labour.

The association of emotion with interruption in the mind shows why mental conflicts are accompanied by anxiety. When one tendency in the mind fails to compromise with a contrary, it sometimes overlays the other as if it were not there. The physical aspect of the process is inhibitory. Two excitations in the cortex are active but one takes precedence. Then the mind experiences an emotion of anxiety due to a conflict between tendencies only one of which it is aware. The anxiety may be ascribed to a wrong cause, for instance, a man who will not admit to himself that he has fallen in love with his typist, may always complain at home of smelling

imaginary gas-leaks. He has interpreted the anxiety from his conflict of affection as due to dangerous gas escapes.

Those mental experiences called belief and doubt are emotional. The first is due to the disposition, which is related to the character of his nervous physical organisation. When a man is described as sceptical, bigoted, prejudiced or changeable, the character of his emotional disposition corresponding to his nervous organisation is being described. When a man has an experience this emotional equipment will immediately tend to react according to its character without his being aware of the fact. Feelings of belief or doubt when analysed are found to be emotions of joy or fear. Belief emotions can be classified into feelings of expectation, bare assent and familiarity. They are less intense than the simple fundamental emotions. Nervously, they are concerned with parts of the brain higher than those concerned with the fundamental emotions. In pathological cases emotions of belief and doubt may achieve great strength, often without having a clear notion of what is believed or doubted. Persons drugged with nitrous oxide or the American Indian's mescal have enormously strong beliefs while under the influence of the drug. The feeling disappears as the influence of the drug wanes. These observations are interesting in reference to the fact that persons with intense beliefs are often of changeable opinion.

They behave as if a drug were secreted in their system which while operative made them believe in one thing, and as it dissipated, the belief disappeared. The next discharge of secretion caused the next belief to be held with the same exaggerated intensity. Or perhaps the behaviour could be conceived as due to short-circuiting in the brain. Higher systems of nervous passages suddenly receive an inruption from lower passages con-

cerned with the messages of the fundamental reflexes. The belief suddenly receives a heavy leakage current from the nervous activities associated with the operation of the primitive emotions of joy, fear, pride or humility. For these reasons, strong beliefs or doubts are always to be suspected. They may be due to an exceptionally harmonious organisation of the mind or brain, so that the subtler processes are operated with exceptional force. A genius may hold opinions on certain questions with an emotional strength of extraordinary order, equal to those, perhaps, of an ordinary man's for his mistress. This is due to the perfection with which the finer parts of his mind co-operate. Though each is delicate, together they make a strong structure, as the delicate parts of an aeroplane when subtly organised produce a structure of surprising strength. Exceptionally strong beliefs in normal persons are usually a sign of leakage of energy from primitive into higher emotions.

When the mind or brain has developed the habit of reacting to certain stimuli according to a pattern, action occurs before thought. It may be that the thinking on the question was done before once and for all, but generally the thinking is done very inefficiently or left unfinished. But the action is always the same, as the pattern controls. Presently the pattern, whenever it is operated in the mind, begins to draw some emotional sustenance from irrelevant emotions. Because the man has a certain mental pattern, an opinion, he receives payment from those holding this opinion. Presently his existence and that of his wife and family become dependent on his continuing to hold the opinion. The pattern in his mind, made originally with little clarity and strength, begins to receive great emotional strength. Perhaps, as time passes, he discovers the opinion is not as clear as he believed at first, and that his thinking was slipshod. Then a conflict arises with what is now a

prejudice, and what he knows to be prejudice, an opinion held with a strength disproportionate to the evidence for it.

LI

THE RIDDLE OF THE SPHINX

THE conflict of desires demands a reorganisation of opinion if one is not to be inhibited as a unit by the other. Sometimes the problem of reconciling contradictory desires is too difficult for the mind, which proceeds in the future to admit the existence of one only, and denies the existence of the other so that it does not rise into consciousness. When this repression happens in a person the motives of his conduct in many situations are plain to everyone except himself. He will sometimes become an ardent scout master from an announced desire to help the youth of his country and fellow men; whereas other persons see plainly that he has been frightened of his normal passions for women because of the responsibility and problems the expression of them is liable to bring to him.

The baby is at first entirely dependent on its mother. From the beginning its reflexes are conditioned to its mother's activities. Its mother is the agent through which all its desires are realised. Consequently the complex of feelings directed towards the mother is from the beginning complicated and strong. Gradually other groups of interests for other near persons grow in the baby's mind, particularly for the father, brothers and sisters. In the early years the mind is so informed that several strong groups of interests can exist without interfering with each other. But as the interests become more defined the child begins to realise that they are not always compatible. If he is a boy, he may find his affection for his father is insufficient to make him

acquiesce in the attentions his father requires from his mother and which diminish the amount of attention his mother can spare for him. The little boy wishes his father away and to supplant him. Freud believes that the desire of the boy to take his father's place may be sexually definite, the degree of the definition being in proportion to the child's knowledge of the Riddle of the Sphinx, that is, how he came to be born. Thus the child's theories of his origin are profoundly important. His understanding of sexual processes may deeply influence his attitude to his parents. Ignorance may inflame the incipient conflict with his father until severe repressed complexes develop. These exist unconsciously through his impressionable years and give him an unreasonable vehemence against authority, one so great that he is inhibited from learning, since if his complex causes him to believe all authority is bad, he will always be anxious under and resent instruction, just during the period of development when his mind is most plastic. This great complex is called after the legend of Oedipus, who guessed the Riddle of the Sphinx, became a king and married the reigning queen, discovering ultimately that she was his mother.

These desires common in children account for the existence of many adult perverts. These have not succeeded in growing out of early incestuous and homosexual tendencies during comparatively innocuous sexual immaturity. The necessity for accurate and intelligent sex instruction of the young is one of the most important lessons to be learned from modern psychology.

Repressed complexes often obtain disguised expression in dreams. During sleep the operations of the mind and brain are different from those during waking. By analysis of the patient's dreams the analyser may be able to discover the nature of the complexes upsetting

his behaviour. Anyone who attempts to keep a record of his dreams will be surprised by their frequence and variety. Many in the habit of believing they dream very little, would be much surprised if they kept a book by their bedside and jotted down the elements of each dream as soon as they awoke. Evidently there is a powerful mechanism of forgetting, which prevents the mind from remembering much of what occurs in it. This is to be expected from the influence of inhibition of the brain both in sleep and consciousness. During sleep and waking much of the brain is inhibited. Waves of inhibition causing forgetfulness are to be expected. In Freud's terminology, forgetting is due to the famous Censor, that spirit of the Unconscious who prevents us on behalf of repressed complexes discreditable to ourselves from remembering disagreeable things.

The great achievement of modern psychology is the demonstration of the extent and importance of unconscious wishes. Different schools of psychologists find different sources of motive power operating the mind, but all are agreed on the framework of theory which gives unconscious activities a large part in mental operations. Freud finds the motivation of the mind in sexual libido, though his definition of sex is wide enough to include other primary urges. Adler finds the motive power coming from the will to live, the ego. When the organism has organic defects it makes special efforts to overcome or compensate for them by excelling in other directions. Many men of genius have had serious defects, Byron was lame, Newton was an extremely delicate infant, Napoleon was unable to hold his own as a child, many distinguished men have been impotent, and so on. If the defective organism cannot discover a special ability of some kind and loose thwarted energy into its development, serious disorder may arise. The organism relapses into activities which attract attention

irrespective of their value. He becomes ill in order that he may receive attention he could not gain otherwise; such cases provide a considerable part of the income of every medical doctor.

Jung stresses the immediacy of the origin of mental disorders, as against Freud's origins in infancy and Adler's in constitutional defects. The comparatively normal person may be presented with moral problems too difficult for him to solve, these lead to mental disorder. The function of the psychologist, according to Jung, is to persuade the patient to perceive the nature of his disorder, face the facts, come to a decision about them and re-educate himself to carry out the decision. Jung's critics say that the patient usually knows what he ought to do, but cannot discover why he is unable to bring himself to do it, and this is the problem psychoanalysis must solve.

The ordinary person will recognise, perhaps, that each of these psychologists has made a great contribution towards comprehension of the mind. For him none of the theories will be entirely right except in what is common to them all, the insistence on the importance of unconscious motives in behaviour. Nor will he be mystified by terms such as the Unconscious, the Censor, the Oedipus Complex, etc., the picturesque and stimulating terminology for phenomena and mechanisms equally describable in terms of the prosaic processes of excitation and inhibition.

LII

THE ORIGIN OF CIVILIZATION

For a million years primitive men wandered over the world, leaving by chance their corpses in China, England, Africa, Java, and other scattered places. The

fossilised remains have by chance been found in these countries, showing that man and his ancestors had been there. Evidently natural obstacles of mountains, jungles, rivers and seas were not sufficient to deter primitive man from penetrating nearly everywhere. If the penetrations were slow, he had hundreds of thousands of years in which to make them. During this long nomadic period he lived entirely by hunting animals and plants.

His life was devoted to the search for food. Since edible animals and plants do not usually occur with great abundance in any one place, the world was for him sparsely victualled, and the world-population of men very small. The rarity of primitive men's remains confirms it. With a huge Earth and few people there was plenty of room and the primitives were not forcibly thrown together in any permanent form of social life. It is possible that primitive men under these free conditions and intensely preoccupied with hunting had no sharp social questions to discuss, and lived together amicably. Some influential schools of modern anthropologists do not agree with the notions of primitive man as "red in tooth and claw", they see primitive times rather with Dryden's vision, "when through the woods the noble savage ran".

Anatole France has written "to think is to be unhappy". Thought appears to have been one of the sources of man's later misery. The desire for life is the overmastering urge common to men, animals and all living things. Primitive man in the moments spared from the search for food appears to have speculated on how he could better preserve his life. He approached the problem scientifically.

Two phenomena particularly impressed him as having special significance for life: blood and sex. Animals and men died when they lost blood. Blood therefore

was life; a brilliant observation so far as it went. Transfusions of blood became one of the methods of trying to revive the dead, and blood-offerings were supposed to vivify other persons, tribes; and later, kings. To ensure more life to the gods and hence to themselves, blood was let from the life-giving sexual organ of the male by incision, and a simple cut evolved later into circumcision. Perceiving that blood is red, the primitive speculators advanced to further abstraction and deduced that life depended on redness. The mere painting of the body with red materials was sufficient to assure it more life. Red ochre became important as a body-stain, and large quantities of it are often found in primitive burial-places, and in the burial-places of surviving primitive peoples such as the Tasmanians and Bushmen in recent times.

The other source of life naturally was associated with sex. Women were observed to give birth to children, and therefore procreative activities were thought to be associated with the essence of life. If these activities were performed a quantity of the essence of life was released in the neighbourhood and entered into those requiring vivification. Later the essence of life was believed to be associated with objects that looked like female genitals. Cowrie shells which resemble the female vulva became objects of life-giving power, charms against death and bad luck. Cowrie shells have been found in some of the burial-places of primitive men.

Like the early primitive men, the Australian aborigines live by the hunting of animals and the gathering of seeds. The seeds of grasses and roots of various plants are laboriously collected, but the idea of cultivating seeds in one place to save the trouble of searching for the wild plants is undeveloped, though some Australians used to replant the roots of some plants they dug up. They try to make unsuitable roots edible

by cooking. In favoured areas life was less nomadic. The Nile valley was a region of this character and was occupied in early times. The "gathering" life was probably lived over most of the Sahara area during the immediate post-glacial period when it was a vast grassland region. In this period access to the Nile valley was easier than later when desiccation made the desert almost impossible and isolated the valley. The nomadic peoples probably found wild barley there which caused them to restrict their movements and become limited nomads. It has been suggested that some genius among them, observing that the water of the Nile helped the barley to grow, thought of extending the areas of wild barley by scooping channels to irrigate more land with the river water. This was the crucial invention leading to civilization, some believe. If this is true, civilization was primarily the invention of an engineering genius, and not of a politician, priest or humanist. Modern industrial civilization also owes more to engineers than politicians, but the modern inventors did not achieve the fame of those of primitive Egyptian antiquity. The tendency to remain in the valley of the Nile and increase food supplies by irrigation was the curb which completed the first suppression of nomadism. By living continuously in one place, the continuity of natural phenomena became more observable. The early irrigator on the Nile became aware of the exact periodicity of Nile floods and could prophesy their advent. He found that the date of the flood coincided with the reappearance of the star Sirius in July. His fellows concluded that he caused the Nile to flood, since he knew when it would occur. Being controller of the Nile and the source of food, and hence the giver of life, this irrigator became a super-man, the first King. The life of such a potent individual became of great concern, for he held the key to the sources of life for all.

Parallel with these settling developments the necessity for systematic burial increased. In the nomadic days elaborate interments of corpses were not necessary since they could be left and the group could move to another place. The burial procedures of the Palaeolithic period existed but were not physically necessary, until the settled groups on the Nile were forced to use them for sanitary reasons. Then the corpses were buried in the sand with astounding but accidental results. The extreme dryness of the climate and sand in Egypt often desiccated them.

During archaeological investigations in 1900, desiccated corpses of pre-dynastic Egyptians were disinterred with many of the main tissues still intact. They had been preserved naturally for nearly six thousand years. The natural preservation of the body must have enormously impressed the early Egyptians and increased belief in the possibility of continuous life. In particular could the kings, those infinitely potent givers of life, be preserved indefinitely? If they could be kept alive, visibly or invisibly, and in a good temper, man's problem of existence was solved. The burial of kings became the most important of activities.

Adopting the naturally given suggestion of preservation, the early Egyptians built special graves for the accommodation of the source of their life. From the construction of graves man learnt the crafts of carpentry and building. Apparently he thought of constructing graves before houses. This is not unnatural, for the grave was to preserve the giver of life itself, whereas a house could have been merely for the trivial purpose of self-comfort. In interpreting pre-history the intensity of the search for the secret of life must always be remembered. Early man tried to discover the secret of creation, and deceived himself that he had found it because he desired so passionately.

The craft of building was learnt from grave-construction, and applied later to barn and lastly to house construction. The storing of grain probably came before self-comfort, and demanded the invention of basketry, from which perhaps pottery evolved later, though this is doubtful. As graves became more elaborate stonework was introduced, and architecture incepted. The architecture and decoration of graves were the cradles of the arts, of sculpture and painting.

The development of agriculture impressed on men's minds the relation between green and life. Young growing vegetation, the new life, was green. So green ointments and cosmetics became important; vital first beautiful afterwards. The bright green mineral malachite was ground into powder and mixed with resin and oils to provide the green pigment. Early mummies often are decorated with this green colour. As the centuries passed the preparers of the green pigment could not very well have failed to discover that a bright brown-coloured metal was obtained from malachite heated in fires. Copper was discovered, and again the advance was a by-product of the search for the secret and preservation of life. Experiments with copper revealed that it could by beating be given a sharp edge capable of cutting granite. The edges lasted only for a few strokes, but the effectiveness was sufficient and the achievement of the great temples and pyramids became possible.

Whether copper or gold was discovered first is uncertain. The Australian aborigines have no use for gold even when nuggets are lying around them, so apparently gold in itself does not necessarily attract primitive man. It must have a use before it becomes attractive and the first of all uses is the preservation of life. It is suggested that there was a shortage in supply of cowrie shells, whose supposed life-giving properties have already

been mentioned. There were not enough of them to meet the demand. Imitations were modelled in clay and beaten out in that yellow plastic material, gold. The advantages of gold charms soon became evident. They were more durable and beautiful, and as their reputation rose the search for gold developed. The Diffusionist school of anthropologists regard this search as a major cause of the diffusion of early culture from Egypt and the Near East. They consider the primary inventions were made in the Nile valley and knowledge of these were diffused by Egyptians and those who prospected for further supplies of the newly valued materials. Ultimately, they say, some knowledge of the inventions of the Egyptians penetrated India, Europe, China, America, and the Pacific Islands. The origin of Maya designs in Central America reminiscent of Indian elephants, animals not found in America, may be explained as the consequence of a trans-Pacific diffusion stimulated in the same manner.

The resemblance of gold to the yellow of the Sun was a reinforcement of the belief in its life-giving potency. Before the first settlements in Egypt, man had noticed that the sexual periodicity in women is monthly, and presumably connected with the Moon. The Moon controlled the life-giving function of women, therefore the Moon shared in the secret of the nature of life. Already having this heavy conviction of belief in the influence of a celestial body on the human affairs, the early Egyptians easily added the Sun and Sirius and the stars to the list of life-givers. They were prepared to look to the sky for potent powers, and presently imagined that was where the mummified kings went to and became immortal. Now they had invented the gods and the theory of the control of life by celestial bodies. Astrology arose and later bore astronomy, a being finer than herself.

The propensity of early man for finding elixirs caused him to canonise the cow. He discovered that humans could flourish on cow's milk and saw that the cow was a source of nourishment, and a life-giver and therefore sacred. The cow became associated with the Moon, and the sky with the cow, and the sky with the heavenly mother.

A cow feeding a man is as a vault over him, so the

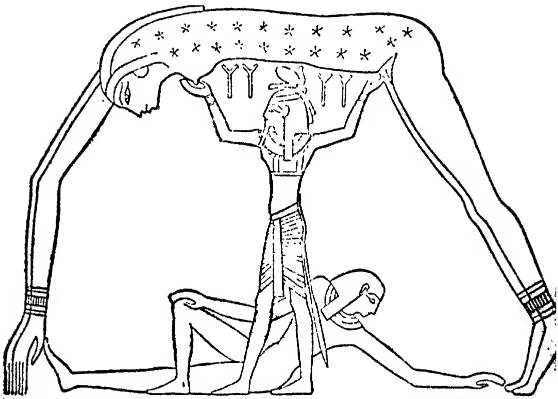


FIG. 123. The Mother-Goddess being raised up to become the Sky.

mother-goddess was identified with the vault of heaven, and the sky was found to be cow-like.

The complicated problems of forecasting Nile floods and celestial movements partly inspired the invention of mathematics. As the methods of producing food and building materials improved, the problems of the ownership of goods arose. Practical geometry was developed for surveying inundated areas so that boundaries could

be restored after the floods. Arithmetic was improved to facilitate the exchange of property.

Property had been invented. Before property, the Diffusionists say, mankind was essentially peaceful, co-operating in small groups to hunt for food, sharing

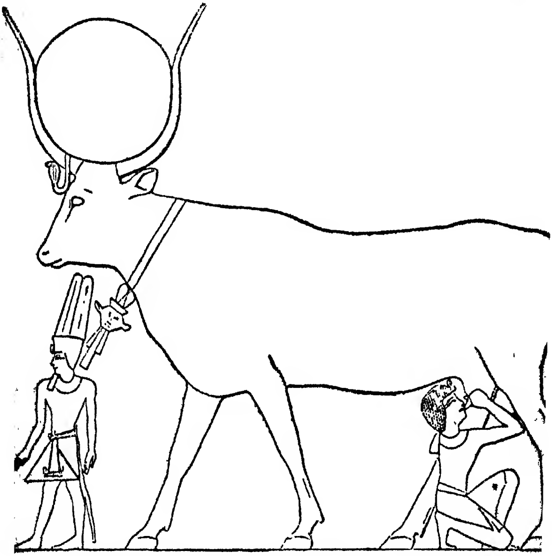


FIG. 124. The Divine Cow giving the king divine life in the form of milk.

and starving together. The invention of property especially in the means of production, was the source of "man's first disobedience, and all our woe". Quarrelling and competition reared their weedy heads in human society.

The first technique for preserving order among the forces loosed by the inventions of civilization was the paternal state. Since the king was the giver of life everyone in the society had been created by him, and all goods his creations had made. The king comprehended all. He knew the secret of creation and was a god, and consequently the head of the religion of the society. All persons and goods belonged to him. He was the owner of everything. His judgment on all questions was final and the order of the society depended on the unity of his own mind. Three thousand years of Egyptian civilization are but variations on this theme.

In this period the germs of most modern ritual are found. The ritual of coronation and weddings have a common origin in the rites for the release of life essence. In the coronation, rites were performed with the late king's mummy, including a kind of drama in which the forces of life and death formed sides and struggled for possession. Later the struggle was restricted to the head of the mummy, and then to to substitutes for the head. From these two sides, struggling for a ball, modern ball-games evolved. From another part of the rites drama evolved, and it is well known that drama was not completely split off from the Church until about four hundred years ago. The spectator at a football match or the theatre is the heir of an evolutionary process already active in Egypt many thousands of years ago. Even the first line of the British National Anthem was breathed out of Ancient Egypt: "God save our gracious King", which was understood by the Egyptians as "God save my life and bring me prosperity". National flags have an equally ancient origin. When a child is born the placenta and umbilical cord by which it was attached to the mother is discharged from the womb. Primitive man regarded the placenta as a sort of twin, so

the king had always a twin, the placenta which accompanied him when he was born. The placenta was believed to have helped in the creation of the child in the womb and therefore was a secret helper, a protecting genius. The king had the placenta carried with him for protection. It was mounted on a standard with the umbilical cord hanging down. In later times a representation of them was carried which gradually

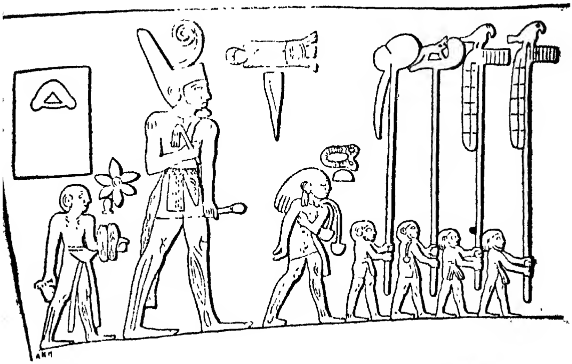


FIG. 125. King Narmer of the First Dynasty in ritual procession. The standard nearest him bears the placenta and umbilical cord, or their representations. From a slate palette of 3400 B.C., containing the earliest known attempt at writing which is not simply pictorial.

after centuries was modified into a flag and red, white and blue streamers, the royal standard.

Constantine the Great introduced crosses into the corner of his flag after his conversion to Christianity, and initiated the custom seen, for example, in the American National Flag and those of the English Navy and Marine.

LIII

THE DEVELOPMENT OF CIVILIZATION

According to the Diffusionists many elements of the culture of the Egyptians spread far across the world. Implanted in Crete it became the foundation of the civilization that flowered there. The Sumerians and the various civilizations of Mesopotamia learned the fundamental inventions from Egyptian sources, and the Indians and Chinese also.

The Neolithic inhabitants of Europe derived much of their knowledge of manufacture from Egypt, and the Persians and Greeks received their first culture from the same source. The Pacific Islanders show degraded relics of Egyptian practices. When culture is diffused it will inevitably be transformed, and improved or degraded. The two tendencies are shown by the Greek and Mayan developments, for the Greeks improved on Egyptian achievements while the Mexicans fell below it. The Greeks were a superior people for several centuries. A number of forces probably combined to produce their achievement. The tribes from which they grew may have been of specially good biological material, and one may speculate that isolated life in the Aegean provinces may have generated by in-breeding from mixed immigrating tribes a few strains of particularly fine men. These tribes in Greece and Asia Minor exploited sea-trade in the Eastern Mediterranean, and their youthful vigour and intelligence enabled them to capture much of it. The Greeks founded a number of cities on trade and sea-routes, and squeezed wealth from the merchandise passing through their hands. The interaction between their high biological quality and their accumulating riches in an environment the reverse of

that of Egypt produced a civilization with many new qualities. The fundamental inventions of civilization could have been made, probably, only in an environment with many uniform characteristics. The valley of the Nile is unique in the regularity of its changes. The combination of rainlessness with adequacy of water supply, the dry air and fertile soil by the river, and the almost automatic variations were the perfect cradle for the unformed mind of primitive man. The natural phenomena of the Nile valley combined variety with almost perfect regularity. The unformed mind was exercised in following them and received impressed habits of orderly thinking from an orderly external world. Egypt afforded an animated lesson in the nature of cause and effect with impressive illustrations too immense to pass entirely misunderstood.

The Nile was the source of a system of Egyptian exercises for the mind. The rigidity of changes in Nilotic phenomena which first disciplined the human intellect, later paralysed it. After humanity had learnt the first lesson, that scientific laws exist, it required a rather more difficult problem to develop its mind further.

It could face complex phenomena after the Egyptian experience, knowing that under chaotic experiences laws probably existed. But the vast and clear-cut cycles on the Nile were simple, and further study revealed no new facts, while meditation on their magnitude increased the sense of awe and inhibited the curiosity of the intellect. Egypt gave the human intellect confidence, even if its lesson in the end wearied from lack of development.

Men in other places having learned from the Egyptians the confidence to question phenomena could now face the ficklest environments without losing their intellectual nerve, and in the struggle with bafflement strengthen their minds. The Greeks around the Aegean Sea were in this situation. The collection of islands connected

by ships dependent on the wind was as a unit at the extreme of difference from the uniformities of the Nile valley. The Greeks were required by their environment to be nimble-witted. Biological chance had given them good brains, and Egypt had whispered her superb secret, that natural laws exist. The interaction of these things produced the Greek civilization. The Greek burgled the intellectual riches of Egypt, and submitted each gem to a fresh and penetrating scrutiny. They saw immediately that there were relations between these gems, that empirical facts could be summarised in theories, and set in a network of reason. The Egyptians had been too near to the intellectual mines to stand back, and perceive that the relations between facts were as important as the facts. This great achievement of the Greeks was the appreciation of the importance of relations and the necessity for observing the relations between phenomena as carefully as the phenomena. It is almost inconceivable that they could have done this if they had not been a culturally infantile people coming freshly on the load of facts the Egyptians had been exhausted in discovering.

In their riot of meditation on facts mainly discovered by others the Greeks evolved the germs of modern thought. They distilled theoretical out of empirical science, pure out of empirical geometry, and philosophy out of practical magic. The creative period of the Greeks was not long enough for the balance of their minds to be demonstrated. Historically they were too theoretical and underestimated the importance of accuracy in accumulating experimental data and fact. Aristotle could organise the collection of data but not the experimental treatment of it. If they had flourished longer the deficiency might have been made up. The facts they had perhaps got too easily, were under-esteemed, and their social organisation of slavery prejudiced them against manual operations and hence against scientific experiment.

The Greek deficiency in empirical investigation was one of the causes of the rise of Roman power. The practical Romans did not follow the intellectual phantasying of the Greeks, but concentrated on economic problems. By their time the productiveness of manufacture and the area of the settled world had increased so greatly that an absolute state-system could afford to be flexible. The improvement of life in Roman compared with Egyptian times is perhaps due more to an increase in material wealth than advance in human ideas.

After the Greeks the next great originators were the Arabians. They were the first to develop systematic methods of experimental science. They made conscious researches in chemistry which produced the new collection of facts from which the theories of modern science evolved. They bore rather the relation to the modern world of the Egyptian to the Greek.

The Renascence expressed a crisis in the steady expansion of wealth in the Western World. But the 13th-century internal trade and commerce between Europe and Asia had crystallised fresh deposits of wealth, especially in Italian cities. The optimism generated by increasing wealth disinhibited the human spirit, and successful gain stimulated the search for more. The intellectual courage born of economic improvement enabled the Renascence men to understand the Greeks, and the spirit of search most evident in sea-voyages designed to discover riches also was expressed in a revival of intellectual research. The Italians learned the art of thought from the Greeks and of practical experiment from the Arabians.

The steady improvement of the technique of production and the appreciation of the gifts from the Greeks and Arabians moulded the Renascence into Modern man, and bred the embryo of modern society.

LIV

MODERN SOCIETY

MAN wishes to live. Civilization was a by-product of his attempts to discover short-cuts to eternal life. He painted himself red and green and searched for gold out of which to fashion charms against death and starvation. The life-desire caused him to invent kings and believe they could bestow life and prosperity. Out of his efforts to foster these mainly imaginary sources of his being the crafts were produced. The application of craft to production commenced that development, certainly the most conspicuous in human history, the improvement in the methods of producing food and those other things tradition dictates are necessities of life. Century after century of reality has not yet succeeded in removing the illusion that magical routes to fullness of life exist. The Mexican Americans cut their ears to produce blood for the vital nourishment of their gods, so that their protectors might remain potent to protect them. Many persons to-day lacerate their bank-balances to vivify the gods of the Stock Exchange, hoping that the waxing of these gods will ensure some droppings of prosperity for themselves. Nevertheless, speculation with wealth represents a great advance on speculation with red paint. The modern man understands at least that wealth rather than magical ideas is connected with the fuller life. In the vanity of his mind man has always tended to magnify the distinction of his spirit. Consequently, improvements in civilization have usually been accompanied by an apparent decline in the quality of the human spirit. The declining nation often prétends to exceptional spirituality; while the rising nation, with closer knowledge of reality has a humbler opinion of itself and the nature of the sources of its improvement.

To-day men worship the job, six thousand years ago they worshipped the king: the change shows the huge advance in human perception of reality. The chief condition of fuller life is that every man should do his job and increase the wealth available for distribution. The quality of human minds is biological, depending on the brain and body. An improvement in mentality is conditioned by biological improvement and is a slow and obscure process. Man does not yet know how to produce better men, so his present task is to learn how to make the most of human gifts as they are. The principles of the manufacture of commodities are fairly simple and well known, and man's immediate task is to develop production so greatly that there is a large margin to ease inefficiency in distribution. It is more important to produce a large surplus of wealth than to study how wealth could best be used. In the past men accustomed to slow progress in the technique of production studied to discover the best methods of applying a limited wealth. They became involved in philosophical questions of rights and values many of which simply disappear when everybody's income is doubled or multipled. Produce the wealth before you discuss what you will do with it! The system of distribution of wealth and the political system associated with it are crude. It is worth asserting that political systems are extremely empirical and that humanity has never had great difficulty in devising political inventions when the environment of wealth required them.

It is easy to see the great changes that have occurred with the ages in production but advance in political theory is much less apparent and probably much less real and important.

The advance of humanity has been due to improvements in production, and as soon as an invention has led to the production of increased wealth the politicians have made some improvement in political technique.

so that some portion of the new benefit should be spread through the community. The statesmen have awaited the products of technicians' creative work and administered them. So the dynamic of progress is furnished by persons ignorant of creative thinking. The difficulties of modern society are considerably due to this situation.

As humanity for ages deceived itself about the efficacy of magic, it has been deceiving itself for centuries about the importance of statesmanship. It is commonly believed that there is such a thing as the art of government, and that persons are best prepared to exercise it after having studied political theory. If the thesis of this chapter is correct political history is a secondary product of improvements in the technique of production, and politicians are not in the first line of creators of civilization. This is the explanation of the spreading belief that somehow our rulers are ruled instead of ruling, and that politicians seem to dance as if managed nstead of managing. The illusion that the art of government exists and can be learned from a study of political history has caused Europe to be governed for centuries almost entirely by persons ignorant of the nature of creativeness. Those who could perhaps have initiated some new technique of government before circumstances had forced it often have their minds pressed into a reactionary mould by a study of the political superficialities of periods with productive techniques much inferior to the modern. It appears that what is called "history" is only a part of complete history and not the most important one. When history is re-written and its dynamic of productive technique exposed, students of history will have the opportunity of meditation on the activities of creative minds. They may carry a little of the spirit of creativeness into their future administrative work and assist society to bring forth necessary political inventions with less travail than at present.

The failure of the traditional type of ruler trained in historical studies is demonstrated by the condition of modern society. These men provided by technicians with tremendous engines of production have failed even to guarantee a decent minimum of food and clothing. Under their rule is a continual rumble of unemployment and social muddle, occasionally boiling up into wars. This inefficiency must be remedied, and is the immediate social task of the future.

Fortunately, the failure of traditional statesmanship is more comic than tragic. Since political is secondary to productive technique the fate of the future rests on production. It is easy to show that the worst political disasters are trivially destructive compared with the constructiveness of applied science. Since A.D. 1800 perhaps 100,000,000 persons have been killed through wars, including the Napoleonic, Chinese and other Eastern wars, and 1914. In A.D. 1800 the world population was perhaps 900,000,000; to-day it is 1,800,000,000. So development in production has called into life several thousand million souls during a period when only a hundred million were sent out of it by desperate political failure. Naturally one is sorry for the hundred million, and their death seems unnecessary and grievous, but the new life created in the same period should not be forgotten. Man is justifiably optimistic of the future since his technicians are creating more quickly than the politicians are destroying through ineptitude.

He must request that the muddle of mal-distribution be cured, and society organised with a thoroughness not utterly unworthy of the quality of applied science. High organisation is possible, as the marvellous organisation of living bodies demonstrates. Man must now try to emulate nature and organise his society as efficiently as nature has organised the community of cells in his own body.

GLOSSARY

α-particles : the relatively heavy positively charged particles ejected from certain radioactive substances and proved to be nuclei of atoms of helium.

Angular momentum : A measure of the exertion required to stop the rotation of a rotating body. In a closed system of rotating bodies the amount of exertion from outside required to stop rotation is constant, though inside the system the members may be continually exchanging portions of angular momentum among themselves.

Antitoxin : A substance produced in a body to react against certain poisons.

β-particles : Electrons ejected from radioactive substances.

Colloid : A substance consisting of particles from about 2/10,000ths to 2/10,000,000ths of an inch in diameter strewn through a more or less uniform medium. The particles are too small to behave like grains of sand and not small enough to behave like molecules.

Dominant : When one of the two (from father and mother) factors controlling a hereditary character dominates the other it is said to be dominant.

Dye-base : A fixed group of molecules from which a dye and its variations may be obtained.

Enzyme : One of a group of substances which promotes chemical reactions in the body.

Extra-galactic : Outside the local universe of stars, beyond the Milky Way.

γ-rays : Emitted from the nuclei of atoms of radioactive substances, a wave-radiation.

Genes : The factors which carry and control hereditary characters.

Heaviside Layer : A region in the higher atmosphere around the Earth which reflects or bends radio-waves entering it. Its existence was suggested by Oliver Heaviside.

Insulin : An internal secretion which enables the tissues to assimilate sugar; lack of it causes diabetes.

Lymph : A colourless fluid circulating in the bodies of vertebrates.

Molecules: The minimum groups of atoms into which substances can be subdivided.

Mutation: A sport or variety which appears suddenly, due to a change in hereditary constitution.

Nucleus of Atom: The central positively charged particle around which the electrons revolve.

Nucleus of Cell: An essential part of a cell containing the chromosomes and necessary to growth and the mechanism of heredity.

Placenta: The organ through which food and oxygen diffuse from the mother to the embryo in the womb.

Proteins: The fleshy parts of bodies (mainly carbon about 50 per cent., hydrogen about 7 per cent., oxygen about 20 per cent., nitrogen about 20 per cent., sulphur about 2 per cent., and phosphorus about 1 per cent.).

Protoplasm: Living matter, a complex of proteins, the "material basis of life".

Radiation: Energy which is manifested in wavy behaviour. Light, X-rays, ultra-violet rays, cosmic rays, radio-waves, γ-rays are examples.

Recessive: One of the two factors governing a hereditary character which is masked by the other (*see Dominant*).

Reflex action: An action determined by the nature of the nervous organisation of the body.

Secretion: Substances produced by glands; the passing of them into the blood and body.

Thyroid Gland: The "Adam's Apple" in the neck. It secretes thyroxin ($C_{15}H_{11}O_4NI_4$), which affects growth.

Ultra-violet rays: Radiation of wave-length a little less than that of light. Tend to kill bacteria, stimulate growth and are the active principle in photography.

Valency: The number of hooks or bonds which an atom possesses for hitching other atoms; a carbon atom has four.

Vestigial: An organ which appears to have degenerated during evolution e.g., the tail of the human, vestiges of which exist at the base of the spine.

Vitamin: A substance affecting the efficiency of diet, the absence of which causes rickets, scurvy, etc.

X-rays: *See* Radiation.

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